Decision Tools for Sustainable Development

DFID Department for International Development

Natural Resources Institute

Sustainable food production and improved food security are major aims of donors and developing country governments alike. Sustaining food production whilst avoiding environmental degradation requires a supportive policy framework and the delivery of appropriate information to facilitate the decision-making process. Better decision-making provides better early warning, improved judgement of risk and better timing of interventions.

Decision Tools for Sustainable Development brings together up-to-date techniques for the collection and management of environmental and socio-economic information. It describes practical decision-making tools for use at all levels from local to international, for rural communities, research services, the food industry and for institutional decision-makers.

The book will be essential reading for research managers, development specialists, government policy-makers, NGO staff and all those who need to make sound and effective decisions for the sustainable development of natural resources.

Decision Tools for Sustainable Development

Edited by

Ian F. Grant and Chris Sear

DFID Department for International Development

Natural Resources Institute

The Natural Resources Institute (NRI) of the University of Greenwich is an internationally recognized centre of expertise in research and consultancy in the environment and natural resources sector. The Institute carries out research and development and training to promote efficient management and use of renewable natural resources in support of sustainable livelihoods.

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INTRODUCTION

The need to increase productive capacity while conserving the environment drives current strategies to alleviate hunger and poverty in developing countries. The goal of donors and developing country governments alike is sustainable food production with improved food security at household to national levels. Sustaining food production while avoiding environmental degradation requires a supportive policy framework. It also needs appropriate and timely environmental information and effective use of methods and techniques that facilitate the decision-making process. Better decision-making provides better early warning, improved judgement of risk and better timing of interventions. It is on these needs that this book focuses. The point of convergence is the development of practical decision-making tools at all levels from local to international, for rural communities, for research services, for the food industry and for institutional decision-makers. A number of decision tools for sustainable development are brought together here as a utilitarian source book.

The techniques available for the collection, organization and management of environmental and socio-economic information are changing rapidly, from appropriate and dynamic participatory techniques to adaptation and use of rapidly advancing information technologies. When applied to the sustainable management of natural resources, these techniques are useful, sometimes critical, decision support tools that can give farmers, extension agents, research managers, planners and policy-makers better powers of spot, judgemental, or process-orientated decision-making, according to their requirements. Information is thus used more rigorously and effectively, contributing to the quality, relevance, uptake and impact of research and development in natural resource (NR) production systems.

Throughout this book case studies are used to show how to make the most of recent developments in the environmental sciences, socio-economic analysis and information technology. It is made clear that decision tools and systems should not be devised and implemented 'top-down', as technologies looking for applications, though some may still be perceived in this light. For example, Scoones (1995) indicted 'modern' centrally based early warning using satellite technologies. He ascribed their poor track record in the livestock sector to the large cost of, and poor information flow from, centralized facilities, lack of respect of end-users for information providers and thus, their information, which was often unsuited to local needs. Scoones concluded that 'satellite monitoring' was a poor solution in most pastoralist settings in Africa. Such techniques, however, have been taken up already and used in a wide range of applications, throughout the world, for example, in insurance, food retailing, commercial farming and forestry, including evolving applications in these areas in developing countries. Thus, rather than 'needing to find a use for the technology', equity and poverty focus now demand that such potentially useful techniques are applied where and whenever possible. We should not dismiss advanced technologies but rather, ask how these technologies can be taken-up equitably to benefit all individuals, including small farmers and pastoralists.

This book draws on decision tools developed for multi-level use, from household and community to state and regional level support. The contributors stress the input of end-users of renewable natural resources in tool development, putting their information needs to the developer and the agronomist and giving them a greater say in the management of natural resources. In many ways the case studies present powerful lessons from recent experience.

What do we mean by a 'decision tool for sustainable development'? Decision tools and decision support systems can be defined as techniques that are designed *with the user* to save time, improve accuracy and quality of judgement and to standardize decision processes, enabling some useful sense to be extracted from ever increasing masses of diverse data and information.

The tools described in this book are accessible to the non-specialist user and include decision trees, data and knowledge bases, entomological models, geographical information systems (GIS), control processes, participatory rural appraisal (PRA) and farmer participatory research (FPR). This book describes expert systems and simulation models that guide users in the use of information, through a 'decision process' that results in the output of useful management information. More diverse and highly specialized systems are not covered here. Systems based on artificial intelligence and cognitive science are deemed to be currently unsuitable for the average non-technical user involved in sustainable development or NR management.

The rapid advances made over this last decade with the help of donor funding are the subject of this book. It draws on multidisciplinary research and development projects from a wide range of NR sectors. Most of the techniques described in this volume were researched, developed, adapted and delivered via projects funded by the UK's Department for International Development (DFID), especially their research and bilateral programmes.

All the contributions to this book are lead by Natural Resources Institute (NRI) professionals whose work supports development and contributes to environmentally sound management of physical and biological resources for sustainable use, now and in the future. The central concern of NRI's work is sustainable development of farming and livelihood systems, with biodiversity and wider environmental issues playing an increasingly important part. This requires extensive development, adaptation and use of the decision tools, such as those examined in this volume.

The book is intended to be a source book for practitioners of sustainable development; decision-makers and managers in a range of roles and whose responsibilities are bounded by a variety of spatial scales, from local to regional. It provides explanations and implementation examples for the prevailing techniques and analytical methods that facilitate sound and effective decisions at different decision-points, from farmer to national agricultural research system (NARS), whilst promoting their adoption, influencing policy and strengthening local institutions. By bringing these tools together in one place, this book will be valuable reading for research and programme managers, scientists, extension agents and policy-makers concerned with sustainable development and management of the environment.

The table below shows the areas where significant advances in decision tools have been made over the last decade with the assistance of DFID funding. Specific chapters engage these subject areas, revealing the links and integration of tools with applications, their impact on development and policy at various levels. The contributions are grouped by the scale of their immediate relevance and each chapter considers decision support tools at a different interface between data ingest and information gathering, and social uptake.

Decision tool	Applications	Development impact	Policy level
Participatory research	Farmer participatory research Local people's knowledge Pest management	Household and community management Research management	Local/national
Risk management	Drought risk management Pest forecasting Expert	Improved drought management Response and coping strategy	National/crisis management
Food security tools	Fumigation support Needs assessment tools Hazard analysis systems	NARS programme and policy Improved food safety and handling systems	National/sectoral planning
Environmental information systems	Environmental monitoring and management	Improved coping strategies Sustainable natural resources	National/regional

Recent advances in decision support techniques are demonstrated in the succeeding chapters. They include the use of participatory procedures, simulation and forecasting methods and higher technological approaches, and the authors make links between the tools and their application within households, communities, NARS, and the policy domains of government.

We have ordered the contributions, broadly speaking, by their main scale of utility, though it is plain on reading them that significant cross-scale linkage occurs. For example, the principles of Hazard Analysis Critical Control Point (HACCP) can and indeed should, be applied at every point in the food production chain, from the field to the supermarket shelf. Also, participatory methods described here can be seen as practical guides for improving information gathering from any stakeholder, not just at community level. Finally, delivering better seasonal weather forecasts can improve crop yield forecasting, drought risk management and better drought planning at national scale but the same information, suitably targeted and interpreted should have potential utility at the local level as well.

Approximately the first third of the book concentrates on participatory methods for gaining information from local communities and on how to add value to that local information and knowledge. It is now widely accepted that people living in rural communities should be seen, not as passive recipients of development, but as active participants in rural development policies, programmes and projects. Key requirements in participatory development include:

- measuring and understanding spatial and temporal variations within rural societies (of local circumstances, individual needs and abilities to respond to opportunities)
- pursuing broad-based participation in development
- building capacity in informal, community-based institutions to
  - access information
  - exert influence on the policy process and thus
  - exert influence on the provision of local services.

Recent wide acceptance of participatory approaches has been carried forward within the agricultural development sphere in farmer participatory research (FPR). A range of projects in the 1990s have included FPR as an important dimension. There is now a substantial body of experience from which to distil lessons in participatory rural appraisal (PRA) and FPR.

The first contribution, by Conroy, Sutherland and Martin (Chapter 1) provides guidance to practitioners of NR research on the best tools to use in FPR. The authors distinguish between different modes of on-farm participatory research: ‘contract’, ‘consultative’, ‘collaborative’ and ‘collegiate’. They explain in detail how the degree of farmer input varies between modes and the characteristics and likely outputs of each. Particularly important is that all ‘farmers’, indeed all individuals making decisions undertake their own research. However idiosyncratic, such research often maximizes the use of local knowledge in the decision-making process. This body of information can be lost to formal research if it is undervalued or not sought out by using appropriate FPR methods. This contribution provides a blueprint for good practice in FPR. By reference to numerous examples from the literature and from case studies, the authors take the reader through the process of FPR from formulation, hypothesis generation and experimental design, to monitoring and evaluation. Separate annexes are used to describe data collection methods and statistical analyses and pitfalls. Taken together, this contribution and its annexes clearly indicate that FPR is not something to be undertaken lightly. If carefully planned and executed, however, it is an invaluable decision tool for sustainable development, focusing as it does at local level, on individual households and on some of the poorest in society. The authors show us how to make the most of this tool.

Chapter 2 primarily considers the linkage between local scale participatory research activities and the institutions formulating, funding and undertaking the research. Drawing on several DFID-funded projects in Africa as examples, Sutherland and Martin present lessons in developing institutional sustainability of participatory research. They show how to link technology and institutional development within NARS, particularly in relation to re-orientating and sustaining the development of institutional capability, to facilitate the adoption of truly farmer-orientated participatory research programmes. The authors use 'issue boxes' to pay particular attention to the roles of NARS, extension services and NGOs, to team building, team leading, managing partnerships and innovation, and also to highlight real-world experiences from case studies. The authors stress the need for a team-orientated approach and team-centred decision-making, providing templates for good practice in project design and in working with farmer research groups. Taken as a whole, the contribution makes essential reading for anyone concerned with participatory research at any level, from practitioner to manager, from project reviewer to government decision-maker.

In Chapter 3, Warburton and Martin analyse in detail an issue introduced earlier in Chapter 1, that is, the contribution of local people's knowledge to NR research and development. Workable knowledge systems (the generation, transmission and application of knowledge) are critical to the development of strategies for sustainable development. In the NR sector, increasing pressure on fragile ecosystems has recently highlighted the need for more attention to be given to local knowledge in the search for appropriate NR uses (uses that do not jeopardize the environment), while supporting and sustaining local livelihoods.

Warburton and Martin analyse the post-war history of integrating local knowledge into development research in the NR sector. They show that people-centred approaches, developed in the last fifteen years, have been more successful than the earlier 'transfer of technology' route which tended to under-value the breadth and richness of the local people's knowledge. Within the context of NR development projects, the authors provide a guide to key questions that practitioners should ask of local knowledge systems, confirming that ultimately researchers should be aiming to enhance local people's capacity to innovate and draw on their own resources. They provide a practical guide to participatory methods that can draw out relevant local knowledge which can be read in conjunction with the approaches described in Chapter 1. Finally, three case studies, covering agroforestry, pest and disease management and soil fertility are used to demonstrate that local people's knowledge is often technical, though couched in different terms from that an external researcher might use. Local knowledge should play a significant role in NR research and development and is a complex interaction of fact, belief and perception, understood in terms of *interactions* between people and between people and their environment.

In the second third of the book, the contributions provide a generally non-technical view of transfer technologies, their adaptation and uptake. For example, pest forecasting can be useful at both strategic and tactical levels. Tactical pest forecasting systems are developed to predict damaging pest events in time for preventative action to be taken by a variety of decision-makers. Forecasters need to receive data that allow them to integrate interactions between the pest, its habitat and the weather, in time to transmit timely warnings. For migrant pests, the data must relate to migration patterns and take account of the geographical scale of the control strategy. Three types of forecasts can be issued: long-term predictions to help officials allocate budgets to plant protection agencies, and medium and short-term forecasts to guide those responsible for the seasonal and ultimately daily deployment of survey and control teams. Expert systems and integrated pest management (IPM) decision tools enable not only forecasts of pest numbers for tactical decision-making but also allow the impact of alternative control strategies to be screened before field-testing. These can provide excellent strategic support, minimizing the calls on scarce research and extension resources.

In their contribution, Tucker and Holt (Chapter 4) show how entomological studies are used in pest forecasting. They outline current attempts to improve the accuracy and utility of operational forecasts in the light of recent research and technological innovation, discussing the use of GIS, remote sensing and modelling techniques in their account of some modern decision tools in IPM. Tucker and Holt argue that environmentally sensitive IPM can minimize pesticide use and improve targeting of chemicals. They stress that understanding farmers' perceptions of pests and diseases and the relative importance of these in terms of the same farmers' perceived exposure to risk is a vital part of undertaking participatory research to develop risk management strategies with and for farmers. Tucker and Holt discuss some decision tools available to researchers concerned with managing the threat to livelihoods presented by migrant insect pests, concentrating on the desert locust and African armyworm and illustrating the information requirements for national and international monitoring and national and local control activities. The authors detail the management strategies currently employed for these two pests. They look at GIS and the remote sensing tools developed by DFID-funded research and used widely in the regional and national forecasting of desert locust populations. Homing in geographically to district level, they explain the derivation and usage of one model to forecast the spatial distribution and timing of armyworm outbreaks in eastern Africa. Technical detail is kept to a minimum and the chapter provides a clear view of the important aspects of model generation including environment and population age structure. In this case, armyworm population dynamics are driven by environmental changes on a week to month time-scale (essentially by rainfall variations). We learn that such modelling and the use of spatially referenced information systems can provide pest forecasting and monitoring with sufficient skill and precision to be applicable at local and district level. IPM strategies must now take these tools and apply them in conjunction with participatory methods to reduce environmental risk and sustain livelihoods in rural communities.

Once a crop is gathered, there is still a great deal of opportunity for loss, damage and spoilage by disease and pest attack, that are critical determinants of food security (or lack of it). In Chapter 5, Hodges brings to our attention decision tools that are used for cost-effective pest management in food storage, using the specific example of control, via fumigation, of insect pests in milled rice stores. Fumigation under gas-tight sheets is a common technique used to disinfest grain stored in bag-stacks in warehouses. Warehouse managers frequently apply fumigation on a regular basis. For example, they might re-fumigate every three or four months, regardless of measured or estimated pest infestation levels. This approach runs the risk of applying the fumigation too late, allowing infestation to exceed threshold levels, causing irreversible damage. It also risks applying fumigation too frequently, wasting resources and increasing the risk of environmental damage and development of pest resistance. DFID-funded research has developed a novel method for assessing pest population levels in milled rice stores using 'bait-bags' filled with brown rice (to which the main pests are preferentially attracted) to monitor infestation. Further research has led to the development of a model to describe the population growth of the major pest of milled rice in store, the beetle *Triboleum castaneum*. Hodges describes concisely and with reference to Indonesian trials, how by combining the new monitoring technique with the computer model, a practical fumigation decision support system has been developed, which can give warehouse managers pest population growth and damage level forecasts and which suggests optimum timing of fumigation.

Funds for agricultural research and development in developing countries are limited and it is essential that work undertaken achieves maximum impact. In the post-harvest area, needs assessment techniques have been developed, validated and employed in systems for handling and processing non-grain starch staple commodities, notably roots and tubers. The beneficiaries of improved needs assessment include farmers, food processing and storage organizations, retailers and consumers. Several case studies have been carried out and reported. In Chapter 6, Westby and colleagues document these and demonstrate the benefits of this approach in sub-Saharan Africa. In particular, the case studies focus on the value of this approach when used by NARS to prioritize their research and development programmes and show how this approach avoids previous criticism that post-harvest research has been technically innovative but subject to poor adoption. As indicated by the authors of earlier chapters, well planned and implemented participation of stakeholders is an essential prerequisite to sustainable development and, according to the authors, no more so than in post-harvest research. They use examples from Tanzania, Uganda and Ghana to illustrate the advantages of suitably adapted informal needs assessment techniques, qualitative methods such as PRA and rapid rural appraisal (RRA), to facilitate effective communication between scientific researchers and farmers and thus improve decision-making in food handling and processing.

Sustainable development requires information and knowledge. Safe food requires effective management of all aspects of food production. In Chapter 8, Nicoliades provides an account of Hazard Analysis Critical Control Point (HACCP) which is a systematic approach to food safety involving hazard identification, assessment and control. It is a more structured approach than traditional inspection and quality control procedures since the process is continuously monitored at key points throughout the process (called critical control points), enabling prompt corrective action to be taken if the process moves out of control. This is in contrast to more traditional 'end point' testing and quality control. Nicoliades includes a precise introduction to HACCP and uses the example of the application of HACCP to small-scale meat processing in Costa Rica to illustrate its use in one part of the food chain. Once again, this contribution is a practical guide to the subject, rather than a theoretical overview and as such gives the reader a rapid and extraordinarily clear view of the concept and one application of HACCP. The principles of best practice in hazard analysis and quality control using HACCP are clearly spelled out and it is worth reiterating the utility of the concept at every stage of the food chain, from field to fork, and indeed when analysing any hazardous activity.

The contributions in the last third of this book consider the uptake of transfer technologies for larger scale environmental monitoring, information management and drought mitigation.

Campbell provides a detailed discussion on the use of remote sensing and GIS technologies in Chapter 8. Environmental information systems now have the capacity to contribute significantly to improving the quality of decision-making. For example, large areas of tropical Africa are occupied by tsetse flies, vectors of human and animal trypanosomiasis. It is commonly assumed that tsetse eradication will improve livelihoods and enhance agricultural production. In tsetse areas, however, changes in land use following tsetse control have often been unexpected and historically have had negative effects on the local environment and on socio-economic welfare. Such changes sometimes have exacerbated the very problems that control operations aimed to solve. Tsetse control is only one of many conflicting issues in rural development and a holistic view of the management of control programmes is required, as it is throughout the NR sector. Sophisticated techniques for acquiring and handling spatially referenced information have an increasingly important role to play in the development of decision support systems and Campbell here uses tsetse control as an example of a successful application of these techniques. For managers of rangeland, wildlife parks and for decision-makers in the livestock sector, this contribution is essential reading, providing a detailed, yet accessible account of handling environmental information in a practical way. The author includes a review of data management issues which is relevant across the range of NR sector research and stresses especially that "unnecessary complexity is a hindrance and will delay utilization of the data, or cause it not to be used at all". He finds that resource managers and decision-makers need to become users of appropriate information systems and to provide the positive feedback needed to turn information technologies to practical operational use.

Using remote sensing and GIS in wildlife park and rangeland management is but one of numerous potential applications of such information technologies in developing countries. As we suggested earlier in this introduction, remote sensing itself has been criticized but techniques in earth observation and information management are now prerequisites for the development of effective decision tools at all levels of society around the world. DFID has been prominent in funding the development of such environmental information system decision tools and their application over the past ten years. Better environmental monitoring and management are now available for uptake in areas such as:

- rainfall estimation, storm, flood and drought forecasting
- vegetation state and land use monitoring
- protected area, park and wetland management for sustaining biodiversity
- fire, forest and rangeland management
- crop yield forecasting
- disaster early warning and management (for example, drought)
- coastal zone management (management of fisheries and ecosystem sustainability)
- pollution control
- ozone forecasting.

In Chapter 9, Williams summarizes these recent advances in environmental information systems. Access to reliable, up-to-date environmental information is an increasingly important component of coherent, multi-sectoral and multi-level decision-making processes. For example, without good environmental information, effective NR management and disaster mitigation are not possible. The challenge in the coming years of a 'global information society' will be equity: to ensure that developing country populations have appropriate access to such information. Williams sets out an opportunistic agenda for the use of information technologies in sustainable development, concluding that increasing coherence in policies, strategies and activities is a requirement for devolved decision-making. Williams argues that integrated environmental monitoring requires a staged approach to survey, mapping and data handling to ensure that decision-making is not fragmented and compartmentalized, in order that affordable and sustainable systems are developed, and to ensure that immediately usable information (data products) are generated for uptake at all levels.

As examples of recent progress towards these goals, Williams examines the DFID-funded Local Application of Remote Sensing Techniques (LARST) initiative, the concept of 'free' environmental data and the application areas which have been developed in the 1990s with local use of low cost remote sensing systems in developing countries. The role of GIS as an information integrator is examined and future developments considered. In summary, Williams re-emphasizes that the need for effective decision support based on environmental monitoring will grow as more and more information floods the world. He concludes that coherent, yet modular, national environmental information systems can meet this need and aid sustainable global development.

In Chapter 10, Sear looks at a global issue – drought – from a regional point of view. Forecasting regional and national environmental change is essential and developing improved strategies for coping with the impacts of global change is imperative. Drought is a recurring problem in sub-Saharan Africa and southern Africa is highlighted to assess whether the improving seasonal weather forecasts that are now being delivered by the global scientific community can be disseminated and used to the benefit of agriculture. First, the author outlines the role of the Pacific El Niño-Southern Oscillation (ENSO) phenomenon in generating meteorological drought in southern Africa. Then he analyses the main requirements of agriculture for long lead forecasts. He discusses the needs of forecast end-users, concentrating on removing obstacles to uptake. Particular attention is given to ongoing activities aimed at improving information accessibility and end-user involvement. A forecast has no value unless it is used and while significant progress has been made in recent years to generate and issue consensus forecasts, little has yet been achieved by way of delivering appropriate, interpreted forecasts to end-users (e.g. to every small farmer in the region). To be used and thus to have value, these forecasts have to be simple to understand, reliable, timely and locally specific. When this can be achieved, seasonal forecasts will be taken-up and drought risk will be better managed. To achieve this, Sear concludes, focused participatory research is needed to determine end-user access to, and use of, forecasts, to determine real end-user need and thus, to encourage a demand to enhance the impact of improved forecasts, as they evolve.

In the final contribution, Sear and colleagues examine the Botswana national drought early warning system as an example of good practice in preparing for disaster and of reducing climate-related vulnerability in a drought-prone country. It is an effective user and filter for meteorological and environmental information, provided initially by the national meteorological service. The national early warning system demonstrably improves government decision-making, has a positive impact on the implementation of drought relief programmes and reduces drought risk in Botswana. The Government of Botswana recognizes the vital role played by the early warning system in coping with drought emergencies. However, it is also now accepted in government, if not yet in rural communities, that drought is a chronic problem for Botswana, which may get worse in the future. Thus, droughts should not be treated as one-off, one year, emergencies but as part of national development planning. The authors analyse the strengths and weaknesses of, opportunities for, and threats to the early warning system and conclude that, in many respects, it does represent good practice as a decision tool, that could be modified for uptake elsewhere in Africa. They conclude that national early systems such as in Botswana can reduce vulnerability to drought and other weather-related disasters. This type of decision tool can help decision-makers to develop strategies to cope better with future change.

The primary conclusion we draw from these contributions and the case studies they present is that the use of decision tools in development has come a long way in the last decade. Their initial slow development, lack of practical application and uptake has been turned around by an improved partnership between user and designer. The user is now empowered to articulate information needs more clearly and the designer is communicating more effectively with the user. The gap between the two has closed considerably, facilitating more effective decision-making at all levels in society. This new generation of tools, perspectives and activities has undoubtedly been enabled by better resourcing, particularly from donor agencies.

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Chris Sear

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Chapter 1

CONDUCTING FARMER PARTICIPATORY RESEARCH: WHAT, WHEN AND HOW

Czech Conroy, Alistair Sutherland and Adrienne Martin

INTRODUCTION

This chapter describes what farmer participatory research is, and when it is appropriate to use it. It also identifies some of the common pitfalls and methodological challenges that research projects face, describes how to take account of them in project design and preparation, and how to tackle them during the course of implementation. In writing the chapter we have drawn heavily on our own and on colleagues' experiences of participatory research[1], as well as on published literature on this subject. Readers are referred to literature containing more detailed information on participatory research methods. This chapter should be particularly useful to practitioners of natural resources (NR) research, including researchers in national agricultural research systems (NARS) in developing countries, international agricultural research centres, and agencies based in the North that are involved in NR research in the South.

TYPES OF AGRICULTURAL RESEARCH

Technological NR research practised by professional researchers may be conceived as three points on a continuum. At one end, strategic research pursues knowledge concentrating on understanding causality and process which have potentially global application. Applied research, mid-way on the continuum, involves using the process and understanding generated by strategic research and applying these to address more specific issues, problems or opportunities with a view to making recommendations. At the other end of the continuum, adaptive research takes proven applied research, or good practice from elsewhere, and makes adjustments for it to work in specific situations and locations.

We should not forget that many rural people (local male and female farmers, artisans, herbalists – hereafter referred to as 'farmers') also conduct their own research, but usually in a more idiosyncratic way than do researchers. Having less time and resources than full-time researchers, but more local knowledge, the majority of farmers are more likely to engage in an adaptive type of research, i.e. trying out ideas

[1]Most of the participatory research projects with which we have been involved have been supported by the UK's Department for International Development (DfID). Two of the authors were involved in organizing a Forum in 1997, at which DfID reviewed its experiences with projects in Africa (Sutherland *et al.*, 1998). The forum and the papers prepared for it have been a valuable source of information for this chapter. In addition, Sian Floyd contributed to the discussion of statistical analysis of data.

and technologies borrowed from others and seeing how they work for themselves, making adjustments along the way. This has implications for the way in which professional researchers manage relationships with their farmer clients.

Different modes of farmer participation in on-farm research

Researchers can conduct research on-farm (or on a local site belonging to a community institution) in a number of different ways, not all of which involve a high degree of participation from farmers. A widely used classification system for different types, or modes, of farmer participation in on-farm research based on Biggs' (1989) typology is summarized in Table 1. The degree of farmer involvement in decision-making varies from mode to mode, and increases in the modes to the right-hand side. The traditional mode, in which the researchers are dominant and farmers least involved, is the *contract* mode. The contract mode involves formal experimentation in specific on-farm situations, but the farmers' views are not actively sought by the researchers.

Table 1 Four different modes of managing farmer participation in agricultural research

	Contract	Consultative	Collaborative	Collegiate
Type of relationship	Farmers' land and services are hired or borrowed, e.g. researcher contracts with farmers to provide specific types of land.	There is a doctor-patient relationship. Researchers consult farmers, diagnose their problems and try to find solutions.	Researchers and farmers are roughly equal partners in the research process and continuously collaborate in activities.	Researchers actively encourage and support farmers' own research and experiments.

Source: Biggs (1989).

The consultative mode, classically exemplified by applications of the farming systems research approach of the early to mid 1980s, includes "diagnosing farmers' practices and problems, planning an experimental programme, testing technological alternatives in farmers' fields and developing and extending recommendations" (Tripp, 1991). In this mode, it is the researchers who provide the solutions, plan the experiments and finally recommend what is best practice. In the collaborative mode, the ideas for interventions to be tested may also come from farmers or other knowledgeable people in the locality, and are the product of discussions between the researchers and NR users. In the case of the collegiate mode, it is the farmers themselves who play the lead role in identifying what the content of the experiments will be, and the manner in which they will be conducted.

The differences between the three more participatory of the four modes are elaborated in Table 2.

Table 2 Specifics of consultative, collaborative and collegiate modes

	Consultative	Collaborative	Collegiate
Researcher and farmer roles	Researchers design trials, provide inputs and monitor: farmers provide inputs and feedback.	Trials are jointly designed and monitored – less dependence on inputs from the researcher.	Farmers design with researcher support and provide nearly all inputs. Joint monitoring.
Selection of participants	Mainly chosen by researchers, based on their criteria, including representativeness.	Jointly determined by farmers and researchers – negotiated. Numbers influenced by farmer interest and researchers' requirements.	Experimenting farmers come forward. If many farmers, numbers may be negotiated.
Rationale	Researchers believe technology developed on a research station will 'work' and wish to test it in farmers' fields with their involvement. (Researchers may consult farmers about priority needs first.)	Researchers and farmers identify priority needs and agree on one or more needs that research can address. Solutions to needs are jointly explored, agreed on and evaluated.	Farmers identify a priority researchable problem or opportunity that they can address with the assistance of researchers.
Objectives	To apply the reductionist scientific method, test hypotheses, try 'best-bets' and decide what will work. Sometimes, to further rationalize the research process and ensure that technical research targets priority groups and issues.	To develop technologies, drawing on both farmers' and researchers' knowledge, to address the felt needs of farmers. To develop partnerships in the research process.	To strengthen farmers' research capacity to develop technology. Develop and empower small-scale farmers' groups, e.g. making demands on research and extension services.
Characteristics	Researchers identify technology to be tested, design trials, provide inputs and instructions. Non-experimental variables managed by farmers.	Farmers identify priority needs where improved technology may assist.	Farmers identify technologies with the potential to meet their needs of the moment. Farmers implement and manage trials.

Table 2 ***cont.***

	Consultative	Collaborative	Collegiate
Characteristics	Research tests researchers' hypotheses using biophysical and socio-economic data – farmers' assessment is supplementary. Researchers concerned to extrapolate technical results.	Farmers and researchers discuss and agree on interventions to be tested, experimental design, data collection and analysis. Farmers make own decisions regarding non-experimental variables. Farmers' assessment is primary in evaluation.	Farmers lobby and communicate effectively with researchers. Less emphasis on diagnosis, targeting, and research resource rationalization.
Outputs	Reliable biophysical data over a broad range of farm types and circumstances. Location-specific information on farmer assessment of technology. 'Recommendations' for extension, based on above, at times particular resource endowment requirements in mind. Feedback for upstream technology design. Farmers' capacity for formal research may be strengthened.	Documentation of farmers' decisions, preferences and management strategies. Biophysical information may be collected on tree, crop or livestock performance from trials that are mainly researcher-designed. Technology options or 'basket of choices' developed – at times related to differences in resource endowments. Farmers' capacity for research is strengthened.	Technologies developed. Farmers' capacity for systematic research is strengthened. Researchers document farmers' decisions, preferences and management practices. Farmers increase demands on NR research services (if their collaborative experience is positive).

Source: Adapted from Biggs (1989) and Coe (1997).

While Table 2 implies some discontinuity between modes, the four modes of farmer participation are probably best thought of as points on a continuum. In practice, the degree of farmer or user involvement in a research project may change over time, gradually shifting from one mode to another. In the early stages of a project, due to significant differences in power and interest between researcher and farmer, the researchers initiate action and the consultative mode is likely to predominate. More collaborative relations can be developed after relations of trust and inter-dependence have built-up between researchers and farmers. This is particularly true for research implemented through NARS organizations, but may also apply to community-oriented NGOs who usually initiate action by deciding which communities to work with, and set limits to the scope of their interventions and mandate.

The advantages of farmer participation

Involving farmers in the design and implementation of research on their farms can provide a number of benefits in terms of the functional effectiveness of the research process (Farrington, 1998). Other things being equal, greater farmer participation means that:

- applied and adaptive research will be better oriented to farmers' problems
- farmers' knowledge and experience can be incorporated into the search for solutions, and highly inappropriate technologies can be 'weeded out' early on
- the performance of promising technologies developed on-station can be tested under 'real-life' agro-ecological and management conditions
- researchers will be provided with rapid feedback on the technologies tested, and promising technologies can be identified, modified and disseminated more quickly, reducing the length of research cycles and saving time and money
- farmers' capacity and expertise for conducting collaborative research is built-up and becomes a valuable resource for future research programmes.

When to take a participatory approach

Farmer participation should not be initiated for its own sake. In many situations farmer participation in research is beneficial, but it is not always absolutely necessary. It is not simply a question of where the research is conducted, on-farm or on-station. (However, it is unlikely that farmers in developing countries could effectively participate in laboratory research.) Farmers can at times usefully contribute to the content of research station trials – for example, crop breeding and variety screening trials (Sperling and Berkowitz, 1994) or conservation tillage experiments (Mellis, 1997; Hagmann *et al.*, 1997). The key issues are: when is farmer participation likely to be (a) beneficial and (b) cost-effective? This may be influenced not just by where the research is carried out (on-farm or on-station), but also by the objectives, the type of technology, the level of risk involved, and the researcher's attitude and objectives.

Project and institutional objectives

Project and institutional objectives have a major bearing on which mode of farmer participation researchers should choose. There are three general objectives that are often associated with farmer participatory research (FPR) projects (Mosse, 1996; Farrington and Nelson, 1997). First, there is the development of technologies to improve agricultural and NR productivity, and also to improve rural livelihoods and food security. A second objective is human resource development (to enhance the capacity of the stakeholders to diagnose problems and respond to them) and a third possible objective is institutional development. The latter two objectives may be linked to a broader agenda, in which the development organizations involved seek to *empower* poorer groups of society.

Government research services are generally concerned with all of these objectives, but emphasize the first. Where this objective is given overriding importance, a mix of the consultative and collaborative modes will generally be most appropriate. Through the application of these modes it is expected that national experts will build-up the skills and experience required to conduct FPR more efficiently, and thereby address objectives two and three. Development projects, particularly those involving NGOs, may also be concerned with all three objectives, but place more emphasis on the second: in this case a mix of collaborative and collegiate modes is the most appropriate. Since this chapter is primarily concerned with NR *research* working through NARS, during the discussion of 'how', we focus mainly on a judicious mix of the consultative and collaborative modes.

Experimental objectives

Whether FPR is appropriate – and if it is, which mode to use – will depend partly on specific research or experimental objectives. Unlike the project and institutional objectives, experimental objectives are largely technical and often technology-specific. There are situations in which anything beyond the very limited involvement of farmers may be detrimental to the achievement of these research objectives, and when the contract mode would be most appropriate. Let us suppose, for example, that a new cereal crop or exotic tree species has been grown on-station, with promising results, and researchers now wish to evaluate its performance under a wider range of biophysical conditions. Research objectives require quantified information on interactions between the technology and the biophysical environment. The interactions will be clearer if other sources of variation are minimized: thus, uniformity of experimental management is desirable, and a researcher-designed and managed trial (as in the contract mode) would be most appropriate for their needs.

Where experimentation has more than one objective, each objective is likely to have implications for data requirements, and for the approach taken. The requirements of the different objectives can be conflicting, necessitating trade-offs between the optimal approaches (Coe, 1997). Where there are substantial conflicts it may be preferable to have separate experiments, with different degrees of farmer involvement. Suppose, for example, one objective is that given in the example above; another is to investigate how the technology performs under farmers' management conditions, and the third is to obtain farmers' assessments of the technology. In this case, one experiment (in the contract mode) is required to achieve the first objective; and a second one (in the consultative or collaborative mode) is required for the other two objectives, which are relatively compatible. The experiments may run in sequence, or in parallel, depending on the project's time-frame and resource base, and the researcher's instincts about the applicability of the technology.

Type of technology

Where the targeted farmers have limited knowledge about the research topic or the biophysical nature of the problem (e.g. viral diseases), or have little understanding of the technical solution on offer (e.g. in the case of biotechnology or pesticide formulation), the benefits of FPR in the more 'upstream' experimental activities are likely to be minimal (Sutherland, 1998). Another, related, consideration is the extent to which participating farmers would have scope for manipulating or adapting the technology being researched. For example, in the area of animal health, vaccines offer farmers very little if any scope for adjusting a technology, whereas antibiotics, acaricides or local remedies offer scope for local adaptation. Similarly, hybrids offer much less scope for farmer participation in their development compared with open-pollinated or composite varieties.

Researcher's attitudes and objectives

If the researcher involved does not believe in FPR, and is only including it as a way of securing funding for academically oriented research, then its value is questionable. Unless this attitude is changed through the process, he or she is not likely to use effectively farmers' opinions and reactions, and is likely to delegate experimental implementation and monitoring to junior staff, and use more resources on logistics than would be the case for on-station research.

Risk bearing

If a high level of risk is involved in the planned research, it will not usually be appropriate to engage a high level of farmer participation. This is particularly true early on in a project, when researchers are establishing rapport and credibility with farmers. When good rapport has been established, researchers can afford to take more risks 'publicly' because the collaborating farmers will be able to understand that to identify a suitable technology, a number of possibilities may need to be tried out on a small scale. Early on this is difficult because farmers who have not been exposed to formal experimentation tend to view an agricultural research trial like an extension demonstration (Ruddell, 1997).

ESSENTIAL CONDITIONS FOR FARMER PARTICIPATORY

Even if the objectives of a research programme or project indicate that collaborative on-farm research would be the best mode to yield the kind of information and outputs that are sought, there are some institutional and methodological challenges that could make it difficult to operate in this mode. These need to be taken into account in the design of research projects. In some cases, when these challenges are taken into account, the conclusion may be that the collaborative mode, while desirable, is not practicable.

Institutional capacity

To implement participatory research effectively certain institutional requirements need to be met (see Chapter 2). First, researchers' organizations and their main collaborators need to have a *commitment* to FPR. Secondly, they should have an appropriate and sufficiently broad mandate. For example, for some projects/technical areas (e.g. watershed management) a wide range of expertise/programme activities may be required: consequently, a research organization that focuses on fodder and grassland, for example, may not have a broad enough mandate to respond to local people's priorities (e.g. water conservation) or to take an integrated approach.

Even if an organization has the mandate, it is often the case that not all of the expertise required is found within it, and it may be desirable for two or more to collaborate on a particular project or programme. National agricultural research organizations and NGOs often have complementary strengths and weaknesses, the former being stronger on technical matters than social ones, while the latter are weak on technical ones, but strong on participatory approaches (Farrington *et al.*, 1993; Farrington, 1998). It should be borne in mind, however, that their objectives may differ, which can give rise to complications. Does the organization have a good track record for effective collaboration with others?

Third, research organizations need the *capacity* to apply FPR – commitment alone is not enough. FPR needs to be undertaken in a flexible manner: a process approach (as opposed to a blueprint approach) is required. Plans, and possibly objectives, may need to be updated and revised periodically. The iterative nature of FPR may not be easily reconciled with time-bound structures and funding. Researchers need to assess whether their organizations and/or their donors are sufficiently flexible to enable them to take a 'process' rather than a 'blueprint' approach to research implementation. If they are not, it may be best not to embark on FPR.

Resources

Human resources

Researchers' attitudes are very important. They should have respect for the views and knowledge of the people with whom they intend to work, and, for example, be prepared to traverse difficult terrain and climates, leave home early and return late, and hold interviews at times that are convenient for local people.

FPR requires staff skills that are often scarce, particularly in some national agricultural research organizations. Expertise will be required in appropriate informal and formal methods for surveys, monitoring and analysis: FPR, and particularly collaborative research, poses many methodological challenges, some of which are discussed later. It may be necessary to have staff from a number of disciplines, so that an interdisciplinary approach can be taken. In addition, it is generally desirable, and sometimes essential, to have at least one woman in the team, to facilitate interaction with female farmers.

Ideally, at least one member of the research team should have had some previous experience of participatory research. There is often a need for training of research staff in participatory research methods. To some extent it may be possible to provide 'on-the-job' training, but if funds permit short (2-day to 2-week) formal courses would be ideal. (For a valuable training manual in FPR, oriented to the collegiate mode, see Veldhuizen *et al.* (1997).)

Financial resources

The financial resources required for collaborative research are often underestimated. Monitoring and analysis may be more time-consuming than they are in more conventional research modes. With on-farm experimentation there is generally more variability in the experimental data than is the case with the contract mode, and consequently data may need to be obtained from a larger number of fields, farmers, etc., if the effect of the technology being tested is to be detected. It may also be necessary to carry out more detailed monitoring of farmers' management activities to explain some of the variability in results between farms. It will also take time (Pijnenburg, 1998), and hence money, to build-up an effective working relationship.

Time

Research projects usually have a fixed duration, which is often no more than 3 years. Research scientists need to consider whether FPR can deliver/meet objectives in the time earmarked for the project, while bearing in mind the need to (a) allow for delays and complications, and (b) develop a rapport and partnership with participants. For example, if they have not worked closely with local communities already, a long lead-in time may be required to develop the necessary rapport to work effectively with them.

METHODOLOGICAL ISSUES IN DESIGN AND IMPLEMENTATION

We have already noted that FPR may be conducted in a number of different institutional settings, and its technical focus may be quite narrow, or very broad. Whatever the case, a project is likely to follow a similar general pattern of activities. The project will:

- 'get started', deciding where to work and with whom; identifying (general or specific) priorities, problems and opportunities
- look for interventions to address these
- design experiments and perhaps further data collection, try out new ideas, monitor and evaluate these
- share the results of the research and (in some cases) consider how to sustain this process of problem/client-oriented research.

A number of issues are likely to arise in this process. The first three parts of the process are discussed below in some detail with reference to scheduling, targeting and participant selection, needs assessment, experimentation and monitoring and evaluation. In addition, aspects of data collection methods and the statistical analysis of data are discussed in Appendices 1 and 2 respectively.

Scheduling

The timetable for the research needs careful consideration. There are often conflicting demands regarding the pace at which research progresses. The short duration of many research projects (often no more than 3 years) may encourage researchers to establish on-farm trials as quickly as possible, so that they can gather data for a minimum number of seasons or years.

On the other hand, it is desirable to avoid rushing because this can undermine the participatory approach as farmers/users are not given an equal say in the design of the research, and they may not develop a sense of ownership. It may be desirable to focus on interacting with fewer farmers and villages during the first season or year so that staff become familiar with a participatory approach. This is a time when effective relationships are developed with participants, research opportunities are identified, and the technologies to address them are agreed.

During the first season or year of experimentation it is sometimes appropriate to adopt an exploratory approach to experimentation, screening a wider range of technologies, with a view to identifying the most promising, and trying new things on-farm on a small scale without replication. Where the approved duration of the research is longer (say up to 5 years), it may be best to have an initial phase of observing farmers' own informal trials or current practices, in relation to selected issues (Edwards, 1987). This helps the researchers understand problems and potential solutions from the farmers' viewpoint, gain deeper insight into the differing problems of individual farmers or sub-groups, and prepares them for participatory research if they are new to it. Observations of this kind can be conducted concurrently with exploratory trials, in which the researcher contributes ideas. Farmers do not usually like being observed by outsiders, but usually enjoy interacting with outsiders, exchanging knowledge and 'material' technologies such as seeds, chemical inputs and local concoctions.

In many cases a preliminary needs assessment (taking a few weeks or months) is followed quickly by exploratory experiments. Through monitoring these experiments and discussion at the end of the season, the process of assessing, and reassessing, needs continues. This works if researchers allow themselves enough time for quality interaction with farmers, carry out genuinely exploratory experiments, maintain an open mind on the problems, and do not insist on repeating the early experiments over several seasons in order to obtain 'conclusive data.'

Identifying where to work and with whom – targeting

Where research is conducted by development agencies whose primary concern is to improve the quality of life of people in their programme area the process of identifying where to work, and who to work with, is relatively straightforward. Researchers, however, are generally expected to rationalize their resources and "identify groups of farmers who have similar circumstances and for whom it is likely that the same recommendation will be suitable" (CIMMYT, 1988). These groups or categories of farmers are usually known as 'recommendation domains'(Collinson, 1981; Franzel, 1981; Tripp, 1986). From a cost-effectiveness viewpoint, this is particularly important given that participatory methods often involve a relatively high cost per participating farmer: if the only beneficiaries were the people with whom the research project was directly involved it would be difficult to justify.

One way of tackling the issue of cost-effectiveness and targeting has been to develop cost-effective methodologies for classifying farming systems and identifying recommendations domains (Collinson, 1981). For the research conducted to be relevant to large numbers of NR users, the constraints or opportunities researched should be ones that are widely experienced. This implies that participants need to be from the principal farming systems in the region concerned. This presupposes that these farming systems have already been adequately described, and have not substantially changed since then (Maxwell, 1984).

Put simply, the following steps are required in order to optimize the extent to which research results can be generalized. The farming systems and farmers must be appropriately classified, and a particular category of farmers targeted. An arena of operation (usually a target area or areas) must be selected in order to rationalize experimental activities. From this operational arena, farmers representative of the main target group are selected for involvement in the research process – from needs assessment, through identification of treatments, to technology evaluation and sharing. To achieve this, a purposive, rather than an *ad hoc*, approach to selection is required. This approach should be aware of, and seek to minimize, sources of negative bias in the selection process including gender bias, wealth bias, middle-person bias and roadside bias (Sutherland, 1986, 1994a).

Selecting farming systems and zones

In determining the areas and production systems in which the participatory research will be conducted, both biophysical and socio-economic factors are relevant. Secondary data sources should be consulted, and full use made of whatever information is already available so that duplication is avoided. In many countries maps already exist that identify the various agro-ecological zones, and government agencies usually have data on the spatial distribution of crop production and ethnic groups.

Some of the information required may, however, have to be collected by the project through short overview surveys, to enable characterization of farming systems in a way that is most relevant to the project. Initial characterization can be modified as further information is collected during the course of a project (Harrington and Tripp, 1985), and if time is pressing target groups can be developed iteratively, during needs assessment, monitoring and on-farm experimentation (Sutherland, 1997a).

If a project is oriented towards a particular commodity or factor, it may adopt a different approach to targeting from one which is oriented to a particular area or category of farmers. For example, a livestock research project in semi-arid north-west India (parts of Rajasthan and Gujarat) is focused on goat-keeping, seeking to address the problems of feed scarcity during the dry season. The main purpose and benefits of goat-keeping vary, and production systems vary accordingly from one area and group to another. Although some of the problems encountered are broadly similar, the technologies required to address them may also vary. Thus, the researchers chose to work in districts that between them represented the different production systems. Multi-locational or multi-production system trials have a further benefit in that as scientists gain a clearer picture of production variability in the on-farm trials (from location to location or production system to production system), so they are in a better position to judge the situations and locations (recommendation domains) in which the new technology could be successfully applied (Waters-Bayer, 1989).

Selection of research locations

Practical considerations will inevitably limit the choice of specific research locations – 'villages', 'communities', or perhaps a network of local specialists. The further away these locations are from the researchers' base(s), and the greater the distance between the participating farmers, the greater the costs in time and fuel, and the less contact there is likely to be between participants and researchers.

Trade-offs may be necessary between the extent to which the locations included are representative, and the resource costs involved. A guiding principle is that well-informed choices are always preferable to the selection, by default, of non-representative situations (e.g. adjacent to research stations, major roads, previous projects, a researcher's home village, etc.).

Where researchers or collaborating organizations have already been working with certain villages for some time, and have developed a good rapport with community members, this may be a strong reason for selecting such villages in preference to others, provided they are reasonably representative of villages in the area concerned. This can save time and resources in that a good rapport with participants already exists, and the project may easily access valuable secondary data about livelihood systems, social and economic composition and problems and priorities.

Identifying participants

Participants are rarely self-selected in consultative and collaborative modes. While voluntary and willing participation are common, participants are normally selected from within the villages or communities that have been chosen because: (a) it is logistically easier for the project staff to engage with participants who are located close together; (b) FPR usually seeks to encourage farmers/NR users to work together so that they can share their knowledge and experiences and learn from each other (Sutherland, 1994b, 1997b).

Who participates, and the options used to foster involvement, should depend largely on: (a) the research objectives in terms of particular topics or issues, or specific target groups; and (b) whether or not the researchers consider it important to be able to generalize from the sample selected to a larger population/universe. A particular topic is likely to be relevant to a particular type of farmer. If extrapolation is to take place, it must be based on some criteria relating to the type of farmer (resource level) likely to find the technology useful. Community-based FPR projects often aim to work with all members of the selected communities, or to give priority to resource-poor farmers and/or women: it is unusual for them to target better-off members of the community, except perhaps where an intervention involves a high degree of innovation or risk.

In practice, however, there has tended to be a bias towards better-off, influential farmers (Martin and Sherington, 1997, citing Ewell, 1988). This is partly because of the procedures adopted for participant selection. Options for engaging participants include: (a) volunteering (as individuals or community representatives); (b) delegation of selection to the community; (c) probability sampling (for a discussion of conventional approaches to sampling in agricultural projects see Casley and Kumar (1988)); (d) guided purposive selection. Researchers have tended to take a somewhat *ad hoc* approach, and/or to favour options (a) or (b), on the basis that they are more participatory than (c) and (d) (Sutherland *et al.*, 1998).

Approaches (a) and (b) tend to bias the selection, skewing participation away from the poorest, for two reasons. First, within communities power is distributed unevenly and often volunteer or community-nominated participants are male and resource richer. Second, for many of the poorest a prolonged involvement in research activities is not attractive, as they are preoccupied with more pressing livelihood issues. FPR projects need to engage in more systematic selection strategies if they want participants to be generally representative or from particular socio-economic groups. The selection procedure needs to be discussed with the collaborators, and agreement reached on criteria and objectives.

Purposive rather than completely random selection is likely to be the most feasible approach. Purposive selection requires a prior understanding of the socio-economic composition of the village or community and inter-household relations so that farmers' views and reactions can be seen and understood in context (Sikana and Kerven, 1994); the project should seek to improve its understanding of the local social structure as it progresses.

Techniques such as wealth-ranking (Grandin, 1988) and social mapping, if used with skill and sensitivity, can provide the kind of information that is needed initially (see Veldhuizen *et al.*, 1997; Pretty *et al.*, 1995), and secondary data should be utilized when available. If the relevant information is not available when the initial participant selection process takes place, and volunteer or delegated sampling is used, the project should subsequently check the characteristics of the participants against those of the community as a whole. Additional participants can then be selected if necessary, to make the sample more representative of the target group.

In practice, participatory research programmes that target the poorer find themselves making a trade-off between engaging the poorest and engaging the willing. Working with the poorest can be costly and difficult (Sutherland *et al.*, 1998; Veldhuizen *et al.*, 1997). Such households often require special support which goes far beyond the scope and skill areas of research scientists, and more properly falls into the domain of well-focused community development programmes. However, in any rural community there is likely to be a considerable representation of households which are poor, and yet have a sufficient resource base (some land, labour and farming skills) to engage in, and benefit from, participatory agricultural research activities. The reality is that often the more productive, even if poor, give help and support to the poorest in a community.

Research objectives are also likely to influence the type of collaborator required. If the research is focused on one or more existing commodities or enterprises then the participants may have to be people who grow the crop or keep the livestock concerned. If the research is testing a new commodity the project staff may decide that it is necessary to select willing risk-bearing participants with more resources (e.g. land, labour, equipment) and/or previous positive experience in technology innovation.

For programmes that run for a long time, there is a question of whether to continue collaborating with the same small group of farmers, or to change every so often. Generally, this issue has to be looked at in relation to research objectives, and to the importance of maintaining rapport and relations with the community. In practice, it is likely to be expedient to maintain contact with some of the more interested farmers over a period of years, and also allow space for new farmers to join in as others decide to drop out or as new opportunities arise as the experimental programme expands. If there is a high level of demand, and 'who participates' has become a matter of great interest on the local political scene, this may signal the need for a meeting to discuss the issue further and see what can be agreed. At this point there may be a case for having a core group of farmer researchers, linked to satellite groups or clusters who also participate less intensively, as was proposed for managing the farmer research groups in Zambia (Drinkwater, 1993).

Needs assessment

It is important that there is clear evidence of demand for the research (for example, in the form of a preliminary needs assessment). If the problem or constraint to be investigated is not regarded as important by the intended participants, they will not actively participate in the research.

A thorough survey may have to be done in advance of receiving project funding, unless project approval procedures allow proposals to start with a broad focus, or there is in-built flexibility. The scale and nature of the needs assessment may vary, depending on the scope of the project and the variability or complexity of the farming systems. Some projects have a broad mandate, and their content is shaped by those priorities of NR users that can be researched. Other projects will be more focused – for example, in line with the mandate of the research organization, which may be limited to one or a few commodities, or by the conditions attached by the donor to the nature of the research. The broader the scope of the project, and the greater the variability of the systems and situations of the target group, the more time and effort will be required for the needs assessment exercise.

Obtaining an accurate understanding of needs and priorities can be difficult and time-consuming, and may require at least two phases of discussions with farmers. Directly asking people their most pressing problems may merely generate well-known 'shopping lists'. Problems are likely to be described in terms of a lack of an input (which the farmer hopes the project will provide): for example, where there has been a decline in soil fertility, farmers may characterize the problem as a "lack of fertilizer" (Pijnenburg, 1998). It is important to identify the underlying cause of the problem, rather than just the symptoms. Getting farmers to rank problems or priorities, starting with the most serious or important, provides more information than simply making a list; it also reduces the risk of researchers distorting farmers' views to fit in with their own personal interests or priorities. Veldhuizen *et al.* (1997) provide useful guidance on conducting needs assessments, including the use of problem-trees to identify underlying causes.

Researchers should seek to increase their understanding of what is required and possible as the research progresses.

Ideally, the researchers assist farmers in tackling their most pressing production problems. However, not all of these problems can be easily solved by improved technologies (although there may still be scope for influencing policies or institutions) and their research institute may not have the expertise (or resources and willingness) to address certain problems. Nevertheless, so long as the issue is a reasonably high priority for the local people, and researchers are also convinced, there is likely to be potential for fruitful collaboration.

Designing trials/experiments

Identifying interventions

In the early stages, the aim of the discussions with farmers is to reach agreement on the research agenda. Deciding on the research agenda is a process which should be based on an adequate understanding of the local farming system, including interactions between various components and enterprises in the system, and who is involved in, decides on, and benefits from the various activities. This understanding will help to reduce a long list of possible experiments, to one or two which are most useful and likely to bear fruit. While dialogue between researchers and farmers in this process is essential, dialogue with other knowledgeable researchers may also be vital, in order to avoid duplication and unproductive experimentation. If a consultative mode is used within a NARS setting, further discussions and consultation with other specialists on the extent of the problem and what can be done about it may be required after the needs assessment (Tripp and Woolley, 1989; Sutherland, 1997c). Within a community-oriented collaborative mode, this is a joint process between the local people and the researchers.

Whatever the mode, to sustain a credible partnership with farmers and other stakeholders, the probable relevance of possible interventions needs to be gauged through careful study and widespread consultation. If researchers are convinced, but the collaborating farmers are reluctant, it may be worth organizing a farmer tour to visit an area where this technology is being practised, or to a research station, before trying to introduce it in an on-farm experiment. The researcher should try and avoid the temptation to tell the local people what to do early on in the discussions. Ideas for interventions may come from any of three general sources:

- members of the local communities
- other farmers or NR users in the region
- researchers (and extensionists), based on their own organization's work or the general body of scientific knowledge.

The local people should be encouraged to develop their own ideas initially. It may be useful to discuss ways in which group members have already tried to tackle the problem previously identified, and what effect this had. Discussions should also screen indigenous technical knowledge and previous experimentation by villagers. Often there are recognized specialists within or near a community, and it may be worth identifying these and inviting them to join in discussions, or making visits to them later for more in-depth discussions.

Box 1 Identifying interventions – an example from the Farmer Participatory Research Project, Uganda

This was a joint project between ActionAid and NRI. The project's farmer participatory research unit began work with the Nganjo women's group in the ActionAid Mityana Project. Initial meetings identified declining soil fertility as a major concern. Discussions with older inhabitants indicated that the decline in soil fertility was linked to a gradual shift to continuous cropping, without any corresponding change in soil management and husbandry practices. Many were aware of some of the causes of soil degradation, and suggested ways to tackle them (mulching using elephant grass or coffee husks, inter-cropping, crop rotations, retaining crop residues, controlling run-off from slopes, tree planting, etc.). There was an apparent gap in local knowledge about other locally available materials suitable for mulching. The unit staff sought additional information through discussions with other scientists, from the literature and from the analysis of a range of soil samples taken from group members' lands. After the explorations with the group, it was decided to test local solutions.

Source: Martin and Sherington (1996).

When to experiment

A difficult question to address is 'is an experiment required, or do we have a solution which can be implemented without following a rigorous process of experimental planning, implementation and evaluation?' While everything new to an area may be seen, in certain senses, by farmers as an experiment, not everything new may need a formal experimental design. Through discussion with farmers, especially those with some experience of laying out trials, it may be possible to classify those interventions which require a formal experimental design, and others which can be introduced or tested in a less formal and less resource-intensive way.

Identifying experimental hypotheses

Once a treatment has been chosen for a formal experiment, it needs to be formulated in terms of a precise hypothesis (Tripp and Woolley, 1989). Veldhuizen *et al.* (1997) stress the importance of hypothesis formulation in the context of the collegiate mode as follows:

> "This is a crucial step in the dialogue between farmers and outsiders. It helps the researchers and collaborators to define more precisely what they want to try out and why, and enables them to analyse more clearly the results of the trial. It is a planning, monitoring and evaluation tool. It helps both parties to understand each other's logic better. It provides an opportunity to check the reasons for the problem and prevents jumping to conclusions about possible solutions".

Further information on how to formulate hypotheses with farmers can be found in Veldhuizen *et al.* (1997).

How many farmers/resource users should be involved in an experiment?

In considering this question it is necessary to bear in mind a number of factors.

1. The cost and logistics of meeting participants and collecting data.
2. The quality of interactions with participants versus the quantity.
3. The time required to process and analyse monitoring data.
4. The minimum number of sample units (fields, animals) required to be able to draw general conclusions and for statistical analysis (if required).

Trade-offs may be required between factors 1, 2 and 3, on the one hand, and the fourth factor. Statisticians consider these issues with particular reference to sampling errors and non-sampling errors: while sampling error may be relatively high with smaller samples, non-sampling errors are likely to be high with large samples (Casley and Kumar, 1988).

Where statistical analysis is planned, the minimum number of sampling units (farms, animals, plots) should, in principle, be based on the number required to show a certain difference (e.g. in yields) between different treatments, or between treatments and controls, at a given (e.g. 80%) confidence level and significance level (see Casley and Kumar, 1988). The margin of error (comprising both sampling and non-sampling error) also needs to be taken into account. Sampling error depends partly on the 'population' sampled: if there is wide variation in the universe, sampling error will be high for a given sample size and design. Thus, it is desirable to have some information, early on, of the degree of variation in the universe.

Where statistical analysis is not involved, there are no hard and fast rules for determining sample size. One suggestion, however, is that in the initial phase, when fieldworkers are learning to work in a participatory mode with farmers, the number of experimenting farmers per fieldworker should be limited to, for example, a maximum of 2–3 villages with 5–8 experimenting farmers in each (Veldhuizen *et al.*, 1997).

How many experiments and treatments?

Since farmers' situations may differ considerably, it will probably be desirable to test several interventions through experimentation. However, more interventions will generally mean that more participants and resources are needed, if statistical analysis is to be done. There may have to be trade-offs between the number of experiments required by the range of situations in which the project is operating. From the point of view of data analysis, it is better to collect meaningful data on a few experiments, or on one experiment with a modest number (3–5) of treatments, than inadequate data on a larger number. However, from the individual farmers' point of view, it may be preferable to have a large number of simple (i.e. with and without or before and after type treatments) experiments which carry fairly low risk and may be superimposed on existing farming practices. There is room for negotiation between researcher and farmer on this topic.

Experimental design

A few general considerations about experimental design and data analysis will be mentioned here: for further details the reader is referred to Veldhuizen *et al.* (1997), Ashby (1986) and Stroud 1994).

Coe (1997) identifies three main types of on-farm trials, according to the extent of farmer and researcher involvement in experimental design and management. Design includes the choice of technology (e.g. tree species and their spacing), while management includes practices involving non-experimental variables that may affect the outcome of the trial: for example, weeding and fertilizer application in a trial looking at the importance of different crop varieties.

In Type 1 researcher-designed and managed trials, farmers have little, if any, influence, which roughly correspond to Biggs's contract mode. In Type 2 researcher-designed and farmer-managed trials, the aim is to compare a small number of technologies, where the technologies themselves are implemented according to a fixed protocol, but the management of non-experimental variables is determined by the farmer. With Type 3 farmer-designed and managed trials the main objective is to study how farmers adapt and adopt technologies.

In farmer-managed trials, researchers will face challenges not experienced in more conventional, controlled experimentation. First, participants are likely to have only a limited amount of the required resource (land area, heads of livestock, trees, etc.) available for experimentation. This limits the number of alternative technologies which can be compared on the same farm, and means that complex factorial designs are unlikely to be feasible. Second, there will be large variation among farmers for farm characteristics and management practices. This will mean that if farmers are treated as replications, treatment differences will usually be less significant than site differences. Careful thought needs to be given to the range of conditions the research aims to cover, and how much control researchers should have over management practices that are unrelated to the experimental treatments but which may affect their efficacy. Third, it is essential that researchers and farmers have a common understanding of trial implementation, because if farmers deviate from what the researcher thinks has been agreed, it may be difficult to meet the objectives of the research.

However, some deviations can provide valuable new insights if probed further by the researcher.

There are a number of reasons for limiting the area on each farm required for experimentation (Bunch, 1989):

- it reduces the level of risk
- it may enable the farmer to carry out more than one experiment simultaneously
- parts of the rest of the farmer's land can serve as natural control plots
- it is then easier for poorer farmers to participate in testing a new technology.

Replications. It will generally be difficult to make replications on one farm, so replications within fields are generally avoided. Instead, 'replications' are made across farms that are spatially clustered, so that participants can easily visit each other to observe and discuss their experiments (Veldhuizen *et al.*, 1997). An exception would be when a highly controlled type of experimentation is planned under a contract mode of operation.

Trial formats – bases for comparison. Experiments seek to test hypotheses by comparing treatments: there must, therefore, be some basis for comparison. In principle, the farmers' plots or livestock where the interventions have been tested can be compared: (a) *before and after* the intervention; or (b) with plots or livestock on which the treatment was not tested (a *with and without* comparison). The *before and after* method has the disadvantage that any changes that occur may be due to extraneous factors that have changed over time, such as rainfall or product prices. *With and without* comparisons are likely to be more reliable than *before and after* if made with the same farmer, but they may result in increased variability if different farms or herds are compared. (Control plots or animals may belong to the farmers who tested the new technology, or to different farmers.)

The choice of approaches may be determined by information constraints, or by participants expressing a strong preference for one or the other. Where possible, however, it may be desirable to use both, given that both approaches are likely to have their weaknesses. The results from the two methods can then be cross-checked to see if they are consistent. If they are not, other factors may have influenced the outcome and may require further investigation.

A common weakness of FPR is that researchers often do not collect adequate baseline data to enable a comparison to be made between before and after situations. The participant farmers may not see the need for this, as they may think it is enough to hold the information in their memories. For the researcher, however, baseline information can greatly increase confidence that the intervention or treatment has made the difference that participants say it has. Once the foci of the experiments and the hypotheses have been identified the type of baseline data needed for comparisons will be apparent. At this point researchers and participants can decide how useful such data would be and with what ease and accuracy (recall errors could be a problem) they could be obtained.

The above-mentioned design issues, and others, should be discussed with participants in what are sometimes called Farmer Experimental Design Workshops (Reijntjes *et al.*, 1992; Veldhuizen *et al.*, 1997). A series of discussions may be required. Researchers may need to remind themselves that the design is as much the farmers' as their own.

Monitoring and evaluation of participatory research

Monitoring and evaluation (M&E) are often referred to in the same breath, as though they are the same thing: they are, however, distinct, albeit related, activities. (For a definition and description of M&E with reference to conventional agricultural development projects see Casley and Kumar (1987).) Monitoring is continuous, while evaluation is periodic. Monitoring and evaluation in the context of participatory research is summarized in Table 3 below.

Table 3 Monitoring and evaluation in farmer participatory research

Monitoring	**Evaluation**
The *continuous* assessment of:	The *periodic* assessment of:
• trial design and implementation by project staff in collaboration with farmers in relation to the joint provision of inputs in accordance to agreed schedules;	• relevance of the experiments for the farmer and the community;
• the degree to which participating farmers are adopting and adapting experiments;	• performance of the project, participating farmers and the collaborating institution(s);
• the wider community's perception of farm experiments; and	• efficiency of the project in responding to changing beneficiary needs; and impact of the project in being able initially to build the capacity of beneficiaries; and
• the degree to, and the quality with, which the collaborating institution is participating with both the project and the beneficiaries.	• collaborating institutions' ability to incorporate elements of FPR within their work and thereafter to gauge the benefits that these changes yield for them.

The nature of the M&E system is a topic that could be covered in the experimental design workshop, or in meetings to plan project activities or review project progress. The following questions need to be addressed: What information needs to be collected? How will it be collected? Who will do what, and when? Difficulty in answering these questions indicates that the experimental design has not been thought through sufficiently.

What data and why?

When determining the data required and why it is required, it is important to take account of how the data will be analysed to produce useful and meaningful results. If farmers are involved in collecting the data they are likely to raise these questions, since they will not want to waste their time on unnecessary activities.

Monitoring and evaluation of agricultural experiments is different from M&E of the project as a whole, but the distinction between monitoring and evaluation still applies. M&E requires a combination of qualitative and quantitative information. *Quantitative* data are required to *describe* what is happening: for example, how many farmers are applying what quantities of particular inputs, and what the effect (if any) is on crop yield, weed cover, livestock weight gain, etc.

Qualitative data are often needed to *explain* what has been happening: for example, why farmers applied a certain level of input at a certain time, or why some farmers applied one weed management regime while others applied a different one. Qualitative data are particularly important in the assessment and evaluation of trial results: for example, farmers' criteria for assessing technologies (e.g. crop or tree varieties) are important.

In Type 3 trials it is crucial to monitor farmer management practices, and also linked variables that have an impact on trial results (e.g. frequency of pest control affects pest levels, which in turn affect yield): this information will help to explain the great variability in outcomes that is likely to be found. If part of this monitoring is quantitative, then it may be possible to model the final outcome to try to explain some of the variability, although this is a challenging and time-consuming task for a researcher to undertake (much of this data still collects dust on the shelves of researchers' offices). Careful thought needs to be given to the frequency of monitoring, and the exact timing of each monitoring event.

Who monitors and how?

In the collaborative research mode both the researchers and the participants will play a role in monitoring. There could be two data collection systems or both parties could keep records of the same data. For example, if livestock weight is one of the variables being monitored the participants may keep records in their homes on their own recording cards or school exercise books, and the researchers might record the same data themselves.

Farmers can be assisted in designing simple formats (sheets or notebooks) for recording the information periodically. Where many community members are illiterate extra thought may need to be given to devising record sheets etc., that are intelligible to them. Various PTD programmes have given calendars to farmers to note important events: symbols can be used where necessary. In some cases, schoolchildren interview at fixed intervals the other family members involved in the experiments and do the recording (Veldhuizen *et al.*, 1997).

Farmers can also be encouraged, or may decide, to monitor each other. Projects can build in incentives for this, such as a farmer to farmer competition with prizes (Sutherland *et al.*, 1997b).

Assessing the effect of interventions

Meetings or workshops attended by both farmers and researchers need to be held at which the outcome of the experiment can be jointly assessed. The results of the experiment are systematically described and discussed according to the criteria defined during earlier group meetings. The original objectives of the experiment, and the criteria for success, are reviewed.

Qualitative assessment. Assessments can be based purely on participants' subjective opinions, based on observation, taste, feel, etc. Where participants' own judgements are the main consideration, their willingness or otherwise to 'adopt' the technology that has been tested will be the main indicator of its efficacy.

Quantitative assessment. If hypotheses were formulated, and relevant variables monitored, some quantitative summary data should be available that can provide a basis for the joint assessment. These could be, the percentage of farmers who rated a technology highly, or the average performance of a technology according to some objective assessment. For example, in an agroforestry project, data were collected on where farmers planted selected species, their preferred uses of different species, their opinions about the effect of the species on crop yields (positive, negative or no effect) and their mean ratings of the species against various criteria (Coe, 1997).

Participants' assessments can be quantified in various ways, including the use of ranking exercises. Matrix ranking is useful in that it also shows the criteria on which the rankings are based. The results obtained by each participant need to be noted against each of the main criteria, distinguishing between the different treatments. The results of all the experimenters can be summarized by calculating averages: simple tables may provide an effective way of presenting this information (Veldhuizen *et al.*, 1997). It is also possible, in cases where farmers have detailed local knowledge, and where formal experimentation would be difficult due to time or other constraints, to use ranking in order to simulate a field trial which can be analysed with standard statistical approaches (de Villiers, 1996).

Statistical analysis. There is often scope for some statistical analysis of data in participatory research. With *farmer-designed* trials quantitative assessment data will be in the form of scores or yes/no answers (for example, did a farmer adopt the technology or not) and such data may be modelled using methods for categorical and binary data (log-linear modelling and logistic regression, respectively) in order to investigate whether there are differences between sub-groups of farmers (e.g. men/women).

With *researcher-designed trials* quantitative data will be a mixture of continuous biophysical data, such as yields, and categorical data such as scores or ranks. In principle, continuous data may be analysed using regression. However, meaningful statistical analysis of continuous *biophysical data* is often problematic in participatory research, particularly in the collaborative and collegiate modes, due to high levels of variability. Thus, it is generally advisable to keep the collection of biophysical data to a minimum in these modes unless farmers want to collect the data for their assessments. However, there are situations where the statistical analysis of biophysical data has been feasible (for an example, see Appendix 2), and the problem may not be as acute as some observers have suggested (Martin and Sherington, 1996). Advances in the statistical analysis of data from participatory research are discussed further in Appendix 2.

Scores can be analysed using log-linear modelling to investigate how farmer characteristics and practices affect the relative performance of the alternative technologies. Methods for ranked data are still relatively basic, unless an *ad hoc* approach is used where ranks are grouped into categories, but at the very least, analysis can show what evidence there is that treatments perform, or are perceived to perform, differently. It should be noted that analysis of this data places few restrictions on the experimental design. In particular, there is no requirement for every farmer to test all technologies, or that overall each technology is tested the same number of times.

CONCLUSION

It should be clear from this chapter that FPR is not something that should be embarked on lightly. Several factors, including research objectives, project resources, staff skills and institutional mandates and structures, should be taken into account before FPR is selected as the approach to be taken by a project. In the appropriate circumstances, however, and with careful consideration of the methodology to be followed, FPR can greatly increase the effectiveness of agricultural research. We hope that the guidance provided in this chapter will assist researchers in determining when to adopt FPR, and in maximizing the benefits generated by it.

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APPENDIX 1 METHODS OF DATA COLLECTION IN PARTICIPATORY RESEARCH

The data requirements of different modes

In the contract and consultative modes, researchers' data requirements predominate, and trials and monitoring systems are designed accordingly. In collegiate research, farmers' criteria and assessments prevail, and it is these evaluations (generally qualitative rather than quantitative) that are useful in providing feedback to researchers and which may generate ideas for more controlled testing.

Collaborative research faces the greatest challenges. There are two reasons for this. First, it tries to satisfy both researchers' and farmers' criteria and data needs, which tend to differ. Second, in this mode researchers tend to need *both* qualitative information (farmer assessments) and quantitative data (non-subjective evidence that the technology tested has had a substantive effect on the problem/opportunity). By contrast, the contract and consultative modes are primarily, if not entirely, concerned with satisfying researchers' data needs, while the collegiate mode is primarily, if not entirely, concerned with satisfying farmers' data needs.

Experiments are usually designed by natural scientists who are unfamiliar with the collaborative mode and whose experience and training are limited to the use of a quantitative approach in controlled conditions, notably on-station. They may experience many challenges and frustrations when conducting experiments under the conditions of the participating primary beneficiaries. Primary beneficiaries may not have enough of the required resource (e.g. land area, livestock heads, live trees) for a conventional experiment. Moreover, the primary beneficiaries will vary from one to another, may have different ideas, or fail to understand clearly the instructions given, and so implement or manage the experiment differently, making analysis difficult. Researchers need to be prepared to compromise.

Another problem is that even where meaningful statistical analysis (e.g. analysis of variance) is feasible, scientists may not know how to apply it (or whether it can be applied) to the situations often found in participatory research. They are also likely to be unfamiliar with, and distrustful of, qualitative methods.

Data collection methods in participatory research

A number of typologies have been used to categorize data collection methods. Some of the commonest ones are: individual v. group, formal and informal, quantitative v. qualitative, and structured v. semi-structured v. unstructured. Several different methods are likely to be used at various points in an FPR project.

No data collection method is inherently participatory. It is the way in which the method is applied and the data are used that will determine whether or not the data collection process has been participatory, as is indicated in Table A1. Nevertheless, some methods are particularly associated with PRA and participatory research. (For a description of PRA methods see Nabasa *et al.* (1995) and Pretty *et al.* (1995).) Visualization techniques, such as mapping and diagramming, are well suited to a participatory mode: they can be intelligible to all, including the illiterate, and provide a tangible focus for discussions.

Table A1 Data collection methods: participatory – non-participatory continuum

	Participatory	**Non-participatory**
Mode	Facilitating–empowering	Finding out–elicitive
Outsiders' role	Facilitator	Investigator
Information owned, analysed and used by	Local people	Outsiders
General characteristic	Use of symbols rather than words or numbers	Written word, numbers
Examples of techniques	Natural resource mapping, matrix ranking, seasonal diagrams	Questionnaires

Source: Adapted from Chambers (1997).

There is likely to be a mixture of group interviews/meetings and individual interviews. Group meetings or workshops are useful at various points during the course of the project: in the identification of treatments or technologies for experiments, in designing the trials, in evaluating the results, etc. Group meetings are valuable for generating ideas, for cross-checking information or opinions and for ensuring that nothing has been overlooked. They also help to develop among the participants a sense of involvement and ownership in the research.

Information collection with or from individuals may be important in analysing differences, and in checking the characteristics of all community members against those who are most active in group discussions about the research. Although information about individuals can be obtained during group meetings, this can lead to group members getting bored if they do not see the relevance.

The process of monitoring trials normally involves individual participants in collecting and/or recording data on the performance, or effect, of the technology being tested. Examples of such data include: yields of crop varieties, pest numbers before and after control measures are applied and livestock growth rates under different feeding regimes. The researchers may keep their own records of this data, and may either copy the participants' data or collect data with participants (e.g. animal weight, rubber tree girth).

Each method, or type of methods, has its advantages and disadvantages – potential or inherent. (See Chambers (1997) for the advantages of PRA versus formal, structured questionnaires; see Kumar (1993) on the use of rapid appraisal methods in surveys and their strengths and weaknesses, especially Casley's introduction and Kumar's overview.) This is particularly important in relation to bias and errors, and there is often a case for collecting similar information through different methods for the purposes of cross-checking. (Triangulation (cross-checking) is one of the principles of rapid appraisal methods, but in practice the cross-checking is usually between different rural appraisal methods, rather than between a rural appraisal method and a method with different advantages and disadvantages.)

Bias and error in data collection

There are strong differences of opinion on the relative merits of formal, structured methods on the one hand, and informal, less structured ones on the other. There is not enough space here to discuss these views in any detail, so the reader is referred to other sources. For a relatively favourable view of the former see Casley and Kumar (1988) and for a relatively favourable view of the latter see Chambers (1997). Clearly, however, the quality of any method is partly a function of the skill and care with which it is applied. One important criterion against which to evaluate methods is their accuracy. Accuracy can be marred, in statistical jargon, by two types of errors: sampling errors and non-sampling errors.

Sampling error. Formal, structured data collection exercises have developed the use of probability sampling to minimize bias in the selection of the people who form the sample. FPR has generally not used probability sampling to select individuals for interview or participation in research, although in principle it could. It is not surprising, therefore, that a common weakness of FPR projects is that there is bias in the selection of participants. FPR needs to develop other techniques for minimizing or managing sample bias (sampling error).

Non-sampling errors. Sources of non-sampling error in data collection (surveys) include: response errors, and errors of recording, coding, data entry and processing. Some observers (e.g. Kumar, 1993) believe that the reliability and validity of the information generated by informal, less structured methods may be questionable in some cases, as their flexibility makes it easier for researcher bias to creep in. Whereas formal, structured (questionnaire) surveys greatly reduce problems of individual bias and erroneous inferences. Others (e.g. Chambers, 1997) strongly disagree.

Optimal ignorance

Another important consideration in data collection is the degree of detail and precision required. This tends to be linked with the costs involved (in time), which have financial implications for the researchers and opportunity costs for the farmers. Researchers need to be careful, therefore, not to be over-zealous in their collection of data, and to be clear: (a) why they want it collected; and (b) how the data are going to be analysed. If participants are asked to collect data they too will want to know the rationale for doing so.

APPENDIX 2 STATISTICAL ANALYSIS OF EXPERIMENTAL DATA IN FARMER-MANAGED TRIALS[1]

The main role of statistical ideas and techniques is to assist in the interpretation of data and to help design studies so that the data can be interpreted in a useful fashion. In the analysis of data, statistical analysis has two major functions. Firstly, it can assess whether apparent effects demonstrated by the data are 'genuine' or whether they could be due to chance. This prevents over-interpretation of the data. A related feature is that statistical analysis allows precision of estimates of effects to be calculated. Secondly, statistical analysis can separate effects which may be partially confounded. As a simple example, farm size and gender may have an effect on the variable under study. However, if men tend to have larger farm areas than women, the effects of gender and farm size will be partially confounded. A simple summary of the data will not separate the two effects and a more sophisticated analysis is needed. Additionally, with datasets where many variables are recorded for each subject, multivariate statistical techniques can be used to explore relationships between variables and/or between subjects.

[1]Most of the information in this appendix is taken from Martin and Sherington (1996).

There has been a tendency among participatory researchers and scientists trained in on-farm research to assume that statistical methods are only applicable to researcher-managed work. However, numerous features of data analysis in farmer-managed research (e.g. analysis of trials where input levels and environments vary among sites) may be amenable to modern statistical methods.

Analysis of variance was developed for comparing two or more treatments in a designed experiment, including factorial experiments. For computational reasons, its use was originally restricted to 'balanced' experiments, where each treatment had an equal number of replicates, but modern computing power has overcome this limitation for multi-factor trials/surveys, as is illustrated by the example in Box A1.

Improved methods to handle hierarchical data have also recently been developed. Such data can frequently occur in on-farm research where some factors operate at a different level to other factors. For example, in an experiment, land cultivation over the whole farm may be done either by oxen or manually, while another factor, such as weed control can be varied within a farm. Similarly in a socio-economic study, some factors will apply to a whole village whereas others apply to individual households.

Analysis of variance is only suitable for numeric data measured on a continuous scale, but extensions of this method (Generalized Linear Models) allow similar analyses for binary and categorical data (logistic models and log-linear models, respectively). Other models can allow for an ordered categorical response, for example, a score of 1 to 4 for rating a crop variety in terms of cooking characteristics.

Statistical software packages

The main statistical packages for implementing the above analyses were, until recently, command-driven, and tended to be used mainly by professional statisticians, whereas the more popular, menu-driven packages did not have the necessary advanced facilities. This is currently changing.

SPSS was the first of the major packages to have a menu-driven Windows version and this will handle most of the required analyses, although its output is not always easy to interpret and it lacks some important details. There is also a menu-driven Windows version of Genstat that is far more 'user-friendly' than earlier versions, allowing non-specialists to gain access to its powerful analytic tools. The other major package, SAS, has a Windows version, but is still mainly command driven. Its menu system has not been developed in the standard Windows mode and is not as easy to use as either Genstat or SPSS. These packages are not widely available to researchers in many developing countries, with pre-Windows, menu-driven versions of SPSS probably being the most common. This is either due to the cost of annual licence fees in hard currency (SAS) or the lack of skills needed to sustain the use of command-driven packages (SAS and Genstat).

Box A1 Application of a linear model to data collected in a farmer-designed and managed situation

An example of how farm characteristic data and monitoring data may be used to understand outcomes is provided by the *Imperata* project funded by the DFID Crop Protection Programme. This project studied farmers' practices in controlling the weed, and their effect on the growth of young rubber trees. This was not a 'trial' as such because there was no intervention but it was similar to a Type 3 trial in that it was entirely farmer-designed and managed, and this meant that there was a high degree of variability between farms.

One of the aims was to investigate how the level of the weed *Imperata*, and farm characteristics such as land origin (three types), farming system (four types), and rubber type (two types), affected rubber growth. Data were collected over a period of 2.5 years, during which time levels of *Imperata* were monitored fortnightly, while rubber growth was assessed at 6-monthly intervals. Plots with a size of 0.5–1.5 ha were monitored on 85 smallholdings. Girth measurements were taken from 50 rubber trees in each plot. The trees were immature ones of varying ages, with a maximum age of 5 years at the end of the monitoring period.

A separate analysis of the effect of a number of factors on girth increment was done for each age group of trees. The analysis consisted of fitting a linear model to the data, using stepwise regression in order to identify the factors that had an effect on growth, and to estimate the magnitude of their effect. Despite the high degree of variability in girth increments of rubber trees over the monitored plots, the evidence that *I. cylindrica* had an important effect on growth was strong for almost all age groups of rubber trees for which the analysis was done. Evidence of differences due to farming system and type of rubber planting material was also convincing.

Source: Suryaningtyas *et al.* (1997).

Chapter 2

INSTITUTIONALIZING FARMER PARTICIPATORY RESEARCH – KEY DECISIONS BASED ON LESSONS FROM PROJECTS IN AFRICA

Alistair Sutherland and Adrienne Martin

INTRODUCTION

Farmer participatory research (FPR) is a relatively new approach in the natural resource (NR) research sector and there is, therefore, no fixed formula for implementing it. Various approaches for introducing and establishing FPR programmes have been tried within a range of institutional contexts. Many of these have been as part of NR initiatives funded by the Department for International Development (DFID) in Africa. The management and staff of institutions hosting participatory research projects were often not fully convinced of the relevance of this approach at the outset. Thus not all projects specifically focused on institutionalizing FPR, but all projects have included demonstration and capacity building in participatory research approaches as key aims. This chapter draws on the experiences of a number of these projects, and seeks to address important questions relating to the institutionalization of participatory research.

During the planning of NR research programmes, important decisions have to be made about the design of research projects and programmes in relation to institutional issues. Some of the more important decisions include:

- where, institutionally, to locate a particular research initiative
- the appropriate management and incentive structures
- team composition and staff selection.

Once the above decisions are made, further decisions are required during the implementation and management of research programmes, including the following:

- how to build a team and provide leadership
- how to develop and manage partnerships
- how to manage farmer participation in a sustainable way
- how to manage innovation and attitude change.

For each key decision area, the chapter summarizes key experiences and outlines strategies which have been found useful in addressing some of the problems likely to be encountered. Brief examples are provided along with references to other texts. The cases relate to NR research programmes in agriculture, but the strategies outlined are, to some extent, relevant to other types of NR research and development programmes.

INSTITUTIONAL LOCATION OF PARTICIPATORY RESEARCH ACTIVITY

In many developing countries the trend is towards greater pluralism in the implementation of NR research activities. Efforts at national co-ordination, for example, through a centralized national agricultural research system (NARS) council, are being renewed, in order to reduce duplication, improve research funding and encourage competitive bidding. There is also recognition, in many countries, that a single institution should not monopolize the research mandate, and that a range of different institutions have a valid contribution to make to the NR research and development process. Looking to the future, this implies that there is likely to be more choice in terms of deciding where a particular programme with a participatory research component could be located institutionally. Possible locations include NARS, national agricultural extension systems (NAES), NGOs and universities. Many projects may bring in expertise from more than one institution. Project implementation may involve an element of partnership, however, for reasons of operational smoothness, one particular institution is usually selected to host, lead and co-ordinate the project.

DFID has funded participatory NR programmes in a variety of institutional contexts. In Zambia, Tanzania (mainland and Zanzibar) and Kenya, participatory NR programmes have been located in government-funded research organizations (Box 1). In Ghana, a project was located in the extension department and in Namibia the project straddled agricultural research and extension directorates (Box 2). NGO-based initiatives have been supported in Uganda, Zimbabwe, Ethiopia and Zambia (Box 3), while in South Africa, a project aimed to strengthen a university-based research institute (Box 4).

Lessons on location

The examples in Boxes 1–4 illustrate that selecting the location of a participatory research initiative is an important project design decision. Initiatives which are started on the margins of mainstream research organizations may be effective in the short term, but run the risk of isolation and virtual collapse when resources and management support are withdrawn as happened in Zambia (Drinkwater, 1997).

Box 1 National agricultural research systems (NARS) experience

Many farmer-oriented research programmes and projects have been hosted by NARS institutions. Three distinct approaches to institutionalizing client-oriented participatory approaches can be identified:

- establishing special farmer-oriented teams with a particular regional focus
- making existing commodity and specialist research programmes more farmer-oriented
- making the entire applied research system more client-oriented.

The first approach was tried in Zambia, with the Adaptive Research Planning Teams (Kean and Singogo, 1988; Drinkwater and Miti, 1997). This approach was effective in building a cadre of capable practitioners, and in getting the concepts of farmer-oriented participatory research accepted as a valid approach by senior research management in Zambia. However, in the longer term, it proved difficult to retain the more capable staff who were lured into the better paying NGO sector. Moreover, separation of systems-oriented on-farm research programmes from the commodity and specialist research programmes led to limited impact and capacity building in this part of the research organization, and to some bad feelings relating to control of resources.

Building the capacity of a commodity programme was tried in the Cashew Nut Improvement Project in Tanzania. This project was effective in moving the research of commodity and specialist scientists into a much more participatory mode with farmers. In the longer term, it also led to a shift in research focus, away from cashew only, to farming systems including other crops as well as cashew (de Waal, 1997).

In Zanzibar and Kenya the programme support emphasized change at a wider institutional level. The first phase of the Zanzibar Cash Crops Farming Systems Project targeted the development of an alternative new export crop to cloves: in the second phase the participatory process led to a reorientation towards a wider range of existing crops for export and local markets. If the project had entered a further phase, this would have been oriented to institutional strengthening of the whole Ministry of Agriculture to use more participatory approaches for planning and implementation activities (Walsh and Harvey, 1997).

In Kenya, rather than set up specific teams to conduct on-farm work, the main thrust of DFID support, through the National Agricultural Research Project, Phase 2, has been to focus on interested researchers based in the regional research centres. They have been encouraged to develop on-farm research activities which are needs driven, discussed with farmers, and address issues in the respective mandate areas of the country (Rees *et al.*, 1997). Prior to the establishment of the adaptive research programme, DFID also funded the Dryland Applied Research and Extension Project (DAREP) within the Kenyan national research system. DAREP had a more specific area focus, and used a core inter-disciplinary team to implement participatory research and dissemination activities as part of Embu regional research centres' adaptive research programme for the semi-arid areas (Sutherland *et al.*, 1997).

Box 2 National agricultural extension systems (NAES) experience

DFID-funded NR participatory research projects located in the national agricultural extension systems (NAES) in Africa have been much less common than those in the NARS. NAES are typically large institutions with broad technical and regulatory mandates. They have a wide range of activities, many of which are difficult to make into projects, having no logical beginning or end. When there is a specific technical problem to be solved urgently, or when national trained manpower in agriculture is limited, the NAES may be a suitable choice. The Larger Grain Borer Project in Ghana focused on a new pest threatening stored maize. It was able to develop technical messages through collaborative research with farmers and disseminate research results within a relatively short time. The established extension infrastructure and the available expertise of extension specialists, traders and farmers were effectively mobilized by this project (Compton, 1997).

The Kavango Farming Systems Research and Extension Project in Namibia is working at the interface between the research and extension directorates of the Ministry of Agriculture. The purpose of the project is to develop a regional capacity for farming systems research, extension, development and training. The farming systems approach has been accepted in principle by both directorates, but its field implementation has been difficult to achieve due to the different management and organizational structures of the two directorates (KFSRE, 1997). Collaboration with extension has been easier as it is regionally based, uses local staff and a decentralized system for planning and organization of activities. The research directorate is centrally directed and commodity based, and the regular involvement of research scientists in the on-farm research activities has been more difficult to achieve in Namibia than in most other African countries.

Initiatives within mainstream commodity and specialist research may have a greater chance of having a long-term influence on institutional behaviour. At the same time, introducing participatory approaches through commodity programmes may cause the technical research focus to be over broadened. In southern Tanzania, a commodity-oriented project grew into a systems-oriented research programme (de Waal, 1997), while in Zanzibar an export-oriented technical research project grew into a ministry level institutional strengthening project.

Starting in the mainstream of applied research within the context of region-specific research mandates, as is the approach in Kenya, may take longer to gain momentum, but the effects will probably be longer lasting.

The main weakness of locating participatory research within the NARS is that these have very limited capacity to address the myriad problems which farmers raise during needs assessment, many of which are specific to particular locations. This is where location within the NAES has a distinct advantage, even though the establishment costs may be higher, and the problem of continuity in research programmes more affected by frequent staff transfers. The Intermediate Technology Development Group (ITDG) experience in Zimbabwe indicates that this is a promising way forward, and a similar view is expressed in relation to a DFID-funded NGO-implemented participatory research project in Ethiopia (Farm Africa, 1998).

Box 3 NGO experience

It is rare for NGOs to concentrate only on research activities, but some do incorporate aspects of research into their development programmes. In Uganda, the Farmer Participatory Research Project aimed to strengthen the capacity of Action Aid-Uganda (AAU) to foster participatory research with resource-poor farmers. Agricultural research was a new activity for AAU. Integrating the farmer research programme within AAU's ongoing community development activities, and linking with national research institutions proved to be a challenge (Salmon & Martin, 1997). Among the reasons for the former was the process nature of AAU development methodology and associated staff changes and for the latter, a lack of mechanisms for joint planning.

In Zimbabwe, Intermediate Technology Development Group's (ITDG) Chivi Food Security Project used participatory approaches to develop technology addressing environmental problems identified through dialogue with the local community. Unlike AAU, ITDG had an established technology development mandate. It was able to draw in technical experience easily and also effectively disseminate the approach and some of the technical ideas beyond the initial project area relatively quickly. The dissemination and adaptation aspects of the approach attracted the attention of the NAES, which decided to use this project as a model for developing a more participatory extension approach (Croxton and Murwira, 1997).

In Zambia, CARE did not have much experience in participatory research and technology development, but was able to recruit staff with this experience from the NARS to implement its food security programme. Having a development mandate and funds for development activities, the CARE food security programme was able to draw in technology and methodology developed in the NARS to fuel its participatory research and development activities (Drinkwater, 1997).

Box 4 University research institute

In South Africa, a DFID-funded project supporting the Institute of Natural Resources (INR), of the University of Natal was started in 1995. It aimed to develop skills and strengthen institutional capacity to meet the agricultural, environmental and technology development needs of local rural and peri-urban communities. In 1996, INR became an autonomous research institute. One component of the project focused on building capacity for FPR within the institute and associated institutions through training courses. However, there have been major challenges in building broad-based capacity in the institute and in transferring the knowledge gained through the training experience into changed approaches on the ground. Without core funding for research and development activities, INR management have found it difficult to commit their staff time, both to full participation in the training provided and to implementing participatory research with local communities. Uptake of ideas by most of the associated institutions has also been slowed by lack of strong support for the use of participatory research approaches by senior managers in the related institutions (personal communications with various individuals). However, effective uptake of new ideas has been achieved in instances where those trained have an ongoing programme with resources, and staff have the autonomy to implement the programme in a way they feel best (Sutherland, 1997).

Ultimately, the choice of location should be guided by the programme or project objectives. Where capacity building objectives loom large, support from senior management and resources for sustained implementation using participatory approaches are important for the lasting institutionalization of participatory research. If the objectives are more technical, with participation as a means to improving technical output, senior management support is less crucial. Strategies for making the decision about institutional location are detailed in Box 5.

Box 5 Strategies for location

Conduct a basic institutional assessment of the potential host institutions for a project or programme. This assessment should:

- provide a clear understanding of the institutions' policy, including commitment and understanding from senior management, on implementing participatory client-oriented approaches;
- review the past experience of the institution with participatory approaches and evaluate the current institutional capacity (and resources) for participatory research;
- design a programme within the policy of the host institution, building on past positive experiences of participatory research – if possible involving some of the same staff; if necessary build appropriate training into the project design;
- weigh the relative importance of institution capacity building versus production of technical results: as a rule of thumb, there should be confidence that building capacity in participatory research will improve the applicability and uptake of technical results – if there is doubt that this will be the case, then carefully consider the amount of emphasis placed on participation in the programme;
- if more than one institution is critical to achieving a successful outcome, consider options for partnership in implementation (see below).

FRAMEWORK FOR WORKING TOGETHER – MANAGEMENT AND INCENTIVE STRUCTURE

What kind of a management and incentive structure is required to implement participatory research effectively?

The typical operational structure in a participatory research programme is to have a multidisciplinary team. Usually a more senior professional is appointed leader of a team of colleagues, technical and other support staff. Support staff often include field-based staff in direct contact with local communities. One of the dangers with this type of structure is that the team leader gets over-burdened with administrative duties, and is unable to be effective as a professional. For this reason, the post of administrative assistant is sometimes included in project design to give support to the team leader and free them to make their professional input. This may be possible in an NGO type of organization. However, in government research and extension organizations such a post is more problematic because there is usually an administrative support structure in place; this structure may not always be efficient. The alternative is to delegate administrative functions within the team, including the use of technical support staff for the more routine activities.

Another danger is that field staff become demoralized, being blamed for not understanding unclear instructions, and bearing the brunt of unfulfilled promises made in haste to farmers by the visiting professional staff. A participatory project may not always practise empowerment of its own support staff. Decentralization of decision-making to front line staff within a NR research programme is often necessary for it to operate more effectively (see Box 6).

Box 6 Empowering field staff in DAREP

DAREP had a network of ten experimental and demonstration sites within the project area. During each cropping season (twice per year) farmer open days were held to expose farmers to promising technologies and to listen to their comments on new ideas under experimentation. Initially, the dates for the open days were fixed centrally, at a team planning meeting, mainly so that the team could be sure to attend all the events. However, difficulties were experienced with this approach when, for example, a day chosen clashed with a local market day, with a meeting at the local chief's office or with a school meeting. In the second year of operation, local site management committees were elected by the local farming community. The site committees took on the task of fixing the date for open days and planning the programme. They also took decisions on the content of demonstration programmes and seed bulking activities. Field assistants at the sites operated according to the instructions received from the researchers, but after some disappointing experiences with research trials, they were encouraged to use their own initiative in experimental management. Some went further and conducted their own experiments, in addition to those managed by the project researchers. To encourage this process further, field staff were given training in participatory research concepts and methods. Devolution of responsibility and decision-making had a number of benefits including increased local ownership of the programme, greater variety in the research and demonstration programme and reduced project planning and monitoring costs (DAREP, 1996).

This question of management structure also applies at the level above the project. The management structure of the larger organization, or indeed the management culture of a particular country, may impose constraints on institutionalizing participatory approaches in NR research. Strongly hierarchical political cultures and institutional management structures often make the introduction of participatory approaches more difficult. Participatory approaches may challenge some of the entrenched codes of conduct. Even if a programme does not have a stated empowerment objective, when participation is used as a tool to make NR projects more technically effective, empowerment issues will arise during implementation. Programme designers may want to ask questions such as: "In this culture/organization, is it acceptable to question an instruction given by a superior?, Are staff subordinate in the hierarchy able to take the initiative?, When faced with obstacles during implementation, can they make decisions without consultation?" Negative answers to these questions are likely to indicate potential future problems.

While a participatory research programme may be required to work within a hierarchical management culture, it may do so constructively, in a way that gently challenges and changes part of it. To do this effectively may require using some of the tactics suggested in Box 7.

Box 7 Tactics for using participatory approaches within hierarchical management cultures

- Respect established modes of communication and meeting procedures from the start of the project.
- Invite management to observe or officiate at meetings and events which use other more participatory methods.
- Include training for management in participatory approaches in the budget.
- Spend time explaining new approaches and involve management in planning and decision-making.
- Keep management fully informed of all activities.
- Form a programme steering committee which includes the key management representatives one is hoping to influence.

Incentives

Participatory research holds attractions for some professionals, especially those who enjoy fieldwork and teamwork. However, promotion in many research institutions is based on publication record. Limited opportunities for publication can be an obstacle to attracting high calibre technical personnel to join participatory research programmes. The issue of building incentives into a programme to attract the right type of staff is an important consideration in client-oriented research (Bingen and Poats, 1990).

NGOs, because they can offer their own conditions of employment, are sometimes able to offer incentives to attract a high calibre of self-motivated staff to implement participatory research activities. NGOs also have flexibility in providing packages for individuals and controlling budgets, being less constrained by government regulations. In government institutions by contrast, the issue of incentives often looms large.

Problems often arise when there are disparities of remuneration, such as subsistence allowance rates, between team members involved in similar activities, or between different scientists in the same research organization. In many government organizations, core funding for the research and extension institutions covers staff salaries and basic overhead costs, while field-based work programmes depend largely on external funding sources. As a consequence, a range of donor-funded projects and programmes are often found at any particular research centre. Problems can be created if different allowance rates are paid by these projects. Donors may compete with each other to get the best staff allocated to their projects by offering higher allowance rates than the other donors. To avoid problems, such incentives must be discussed and negotiated with all relevant stakeholders early on in the project. Even if common rates are agreed, not all may be satisfied. Researchers working on participatory research programmes with fewer prospects for publication, or for advancing to Ph.D. level research, may argue that more immediate financial incentives (e.g. higher allowance rates) should substitute for foregone opportunities for publication and academic advancement.

To offset these feelings, funding for presenting papers at appropriate conferences and workshops, can encourage staff to write up research which they (and their colleagues) may otherwise regard of questionable scientific importance.

Incentives are not only financial; working environment, career development, extra responsibilities and if possible, training, are all highly valued. Individuals derive much of their sense of purpose and importance from the work they do. Involvement in a particular project may, in itself, be seen as a form of advancement, because the project will raise the visibility of those involved within the organization, and with other organizations. Having a good working environment, including access to good office facilities (stationery, computer software, modern communication technology and back-up power supplies), reliable transport and a well-structured work programme are all incentives to joining a programme and contributing effectively in it.

In dealing with incentives, the position of team leader requires specific mention. Extra remuneration is not usually provided for this position, even though it carries many additional tasks and responsibilities. Recognition of these extra tasks is important. This may be in the form of some type of renumeration, but verbal recognition is also valued.

TEAM COMPOSITION AND STAFF SELECTION

Most projects and programmes operate on the basis of some type of team approach. However, there is often scope for a more open-ended type of team. In process projects it may be inappropriate to predetermine all of the skills and competencies required. A core team may be agreed, with a generous provision to draw in expertise identified, on a short or longer-term basis, as the programme progresses (for example, see Box 8).

The composition of the team in terms of disciplines is an important programme design decision and will depend on the project objectives. Technical competence in a particular area, but often of a fairly broad-based nature (such as agronomy, livestock production or forestry) is usually a prerequisite. In addition, competence in socio-economic analysis and participatory research methods is essential. Additional specialists can be added as need arises.

Box 8 Example of DAREP team composition

The DFID-funded Dryland Applied Research and Extension Project (DAREP) was implemented by an interdisciplinary team. While DAREP had its base in the Kenya Agricultural Research Institute (KARI) at Embu, the Kenya Forestry Research Institute (KEFRI), the Ministry of Agriculture and Livestock Development, and the Natural Resources Institute (NRI) also provided professional inputs. In the initial project design, the core team proposed was an agronomist, a livestock scientist, an agroforester, an agricultural economist and a social anthropologist. An agricultural engineer was added before the project started, because farmers had expressed their interest in labour-saving tools at field day meetings with extension and research. After the project started, in response to issues raised by farmers and other researchers, further needs were identified requiring input from other disciplines including animal draught power, entomology, parasitology, post-harvest processing, home economics, soil science and biometrics. This additional disciplinary input came from staff who were co-opted into the programme from other KARI programmes, from the Ministry of Agriculture and Livestock Development and from NRI. This arrangement worked well in terms of filling gaps in the team, and was facilitated by a project design and a project management which attached value to multi-institutional collaboration.

Selecting staff for the team

There is often a degree of choice regarding who, within a particular organization, is selected to implement a participatory research programme. The choice may be greatest in those NGOs which have flexible recruitment policies, can recruit staff under favourable conditions of service for a specific programme, and do not feel under a moral obligation to find jobs for staff employed under other projects which have come to an end. By contrast in a government research or extension organization, staff may be transferred from one programme to another, but it is usually difficult to recruit from outside the organization, or to offer preferential conditions of service.

If the programme has specific technical objectives or a commodity focus, staff with relevant experience and competence in that particular area will be sought first. In addition, important qualities include the ability to work as part of a team, good inter-personal skills, a flexible attitude, and the ability to take on new ideas and change opinions. Another important factor relates to the gender of staff. Most agricultural colleges have 10% or less female graduates, and yet having a female on the team is often a major advantage in improving the level of farmer participation. Special effort may be required to recruit and train a female to occupy at least one of the specialist positions.

Selection of the right team leader for a participatory research programme is particularly important. It may be difficult to find someone with the desired qualities within an organization. Bringing in a team leader from outside may not be an option because many public sector research organizations have restrictions on recruitment of new staff. Training a person with potential may be required to ensure that project leadership is provided. In the absence of a strong leader, a modified management arrangement could spread responsibilities across the team, rather than concentrate these on one person. Qualities to look for in a potential team leader are indicated in Box 9.

Box 9 Team leader qualities for participatory NR programmes

- Strong leadership qualities: approachable, fair-minded, having vision and able to inspire others, good communication skills, able to use criticism constructively, ability to see things through, listening skills, humble, able to delegate, able to plan, time management, honest and loyal.
- Experience with management.
- Experience with participatory approaches.
- Holistic and rounded grasp of NR technical issues.

TEAM BUILDING AND TEAMWORK – MANAGEMENT

Guidance about how teams can be formed and managed to function effectively is rarely provided in project documents. Building and managing a team which is composed of people with different levels of experience and different backgrounds is challenging. When some team members seem more committed than others, balancing recognition of personal effort with the development of a team spirit is not easy. Staff appointed as team leaders may have no training in management. As a result, they often experience difficulty delegating, and do not know how to resolve conflicts between other team members, or how to encourage cross-disciplinary working relations. Some tips for building a strong team are provided in Box 10.

Box 10 Ten tips for team building and management

- Take care in the selection of a team leader who should be open minded, able to take a neutral position in conflict situations, and have proven previous experience.
- If necessary, provide the team leader with training on participatory planning, conflict management and facilitation skills.
- Conduct joint activities such as participatory rural appraisals (PRA) together at the start of a project.
- Planning and priority setting should be done as a team activity.
- Hold regular team meetings and share work schedules and outputs.
- Have regular resource allocation meetings and maintain transparency of financial expenditure.
- Have consultation with individual team members about incentives.
- Share responsibilities to avoid team leader overload.
- For productivity and interaction, resources should be optimal; not too many vehicles or computers so that each person is independent, but not so few that team members get frustrated.
- Project design should include flexibility in resource management to allow for creative management of incentives.

Managing the project process

There is a difference between managing a team and managing a project. A team may get along well with each other and with their work, but the sum total does not necessarily amount to an effective project. As a project or programme develops, management challenges arise in steering it properly. A number of options are likely to present themselves in terms of both activities and methodologies for implementing activities. Priority setting is required to aid decision-making about which activity should be done immediately, and which ones can wait, be shelved or even abandoned. Moreover, multiple activities, once started, have to be managed. This requires an adequate understanding of the conceptual links between different issues, activities and objectives. At times, activities are planned for which there is no specialist on the team. Staff who have the wrong skills and may already be overburdened with multiple activities may be assigned to undertake these. The result is that no job is done well. Another danger is that the work schedule may become repetitive after a time, with team members fully engaged in activities, but lacking a clear idea of where the project is heading.

Strategies

While there is no easy solution to managing these risks, some strategies for managing the project process are suggested below.

- *Programme focus.* Areas of focus, both topical and geographical, should be well established during the design or inception phase and clearly agreed within the team. Teams should be wary of trying to do everything and avoid rushing into new activities.

- *Staffing and leadership.* If the right skills for a particular task are not available it may be better to delay this task until the skills are brought in. There should be scope for adding new partners or consultancy inputs. When new members join, an explicit process of training and integrating new team members is required.

- *Continuity.* Continuity of project management and advisory support is important. One mechanism to ensure continuity is to have a deputy team leader.

- *Training/capacity building.* Ongoing skills development and training needs will arise as the project progresses, both for professional and field staff, and these should be budgeted (in time and funding).

- *Planning, monitoring and review.* Participatory annual planning exercises (within the project) should be conducted. An in-house monitoring system (such as regular team meetings and peer reviews of research activities) should be part of the work programme, which feeds into the annual planning and review process. A reflexive learning style should be developed, with the team leader setting an example. There should be an evaluation of the team leader one year into the project.

- *Reporting.* Planning for an integrated information system needs to occur at the start of the project. There should be plans for the use of documentation in project management and this should be tied to project objectives; reports need to be used.

- *Logframes.* In the preparatory/inception phase, a process type of logical framework is required to ensure output flexibility. Only goal and purpose would remain constant. Developing indicators for process management requires much thought.

- *Sustainability.* Develop a continuity strategy with implementing partners well before the end of a project; team members will be wondering about their career path, which should also be considered during decision-making about training.

DEVELOPING LINKAGES AND BUILDING PARTNERSHIPS

A partner: "a sharer, one who engages with another in business, one who plays on the same side in a game, one who dances with another, a husband and wife." *Partnership:* "a contract between any persons engaged in business". (*Chambers 20th Century Dictionary*)

The importance of developing linkages with other institutions has been emphasized in many NR research projects (Ewell, 1989; Merrill-Sands *et al.*, 1991). More recently, the idea of partnerships has come to the forefront. A partnership implies something stronger than a linkage. A mutual unwritten understanding may move into a more permanent arrangement, based on a written agreement or contract.

Project documents often assume linkages will take place, but rarely outline strategies and methods for achieving effective linkages, and developing these into partnerships. The discussion below centres on linkages and assumes that an effective linkage provides the basis for developing a partnership.

The experience of many projects is that successful participatory NR interventions depend on developing and maintaining effective relations with other stakeholders. Effective linkages provide access to new knowledge, ideas and technologies. They can be used to bring additional resources into the programme – financial, technical expertise and local infrastructure. They are needed to establish uptake pathways for technology and developmental plans developed by a programme.

However, establishing and maintaining linkages is expensive, both in time and resources. Stakeholder analysis is a useful tool in helping a team to develop and manage a linkage strategy. In addition, it is important to be clear about the purpose of a linkage – it should benefit both parties. Linkages are usually more effective if they are task-oriented rather than relationship-centred.

Specific problems with linkages relate to different institutional perspectives. NGOs feel they often have a negative image in the government research and extension organizations, which may see them as a threat. They generally find government organizations rigid and slow in making decisions. Territoriality, inequalities and negative stereotyping are common obstacles in developing productive partnerships. Some NGOs have restrictive information policies and fear information piracy. Competition for resources and recognition are often reflected in territorial behaviour.

NGOs often work with local community-based organizations (CBOs), placing emphasis on working through existing groups and the need to understand community dynamics as part of a holistic development approach. In some cases they act as intermediaries between the CBO and government research and extension. From the NGO perspective they are in a position to assess CBO capacity – both organizational and technical – and research/extension needs more accurately than government organizations. They can represent and lobby for delivery of these needs and take an active role in promoting participatory technology development.

Some government research and extension organizations perceive NGOs and their relationship with CBOs as offering a cost-effective way of developing community-based NR activities. From the CBO perspective, the NGOs' role is seen primarily as one of facilitation and monitoring and there is a tendency to undervalue their technical contribution. In contrast, government researchers and extensionists who have operational resources and regional mandates may see no need to work with NGOs. They may seek direct relationships with farmers and CBOs through the government extension structures.

From the NARS perspective, the main problem is poor linkages with the NAES. Linkages based on personal contacts may be difficult to sustain because the senior managers are not always supportive. There are often poor flows of information between researchers and extensionists who are not aware of each other's work plans. This makes co-ordination difficult. Moreover, a hierarchical bureaucratic chain of command with extension hampers horizontal communication. Linkages within NARS are often weak and it may be difficult for adaptive programmes to test and access a wide range of the technologies being developed in the specialist and commodity research programmes. Activity ownership and competition may be an issue at this point. The responsibility for maintaining linkages is not clear – who should take the lead?

As government budgets and development aid becomes tighter, there will be increasing competition between institutions for funds to implement NR research projects. Increased competition has the potential to reduce potential collaboration and information exchange. To reduce unhealthy competition, there will be a need for more partnerships between institutions in the implementation of research activities.

While the perspectives on linkages and partnership differ somewhat between NGOs and CBOs involved in participatory NR research, the strategies proposed to improve these are broadly similar (Box 11).

Moving participatory research into a partnership mode of operation is likely to require co-financing of specific activities. Joint budgeting may not be easy since it is likely to raise such issues as different allowance rates, but should still be tried. Decentralizing funding in programmes could allow better collaboration at field level because local managers would have more flexibility in how to utilize funds in order to co-opt assistance from other local agencies. Project design needs to detail 'why', 'who' and 'how' for linkages and partnerships. If this is too complex a task for the design team, a stakeholder analysis should be part of the inception phase.

Box 11 Strategies for linkage and partnership

- Some form of institutional analysis, such as stakeholder analysis, to develop a linkage strategy for a particular project, mutual benefits and tasks should be outlined.
- Neutral facilitation at stakeholder meetings held on neutral grounds (or rotating venues). Stakeholder analysis should cover issues of philosophy, image, power and current linkage mechanisms.
- Formalization, such as a memorandum of understanding, is necessary to give legitimacy to jointly implemented activities.
- Incorporating linkages into project logical frameworks (in process projects). Objectively verifiable indicators should be agreed for all identified linkage activities, e.g. number of meetings. In long-term projects, objectives for linkages should be periodically reviewed with indicators to be developed against objectives.
- Joint planning, budgeting and where possible joint implementation of activities such as rapid rural appraisal (RRA)/PRA, on-farm trials, field days, paper writing and monitoring and evaluation activities.
- Exchange of work plans and regular task-based co-ordination meetings between linked partners.
- Project staffing should include recruitment/re-location of staff with a positive linkage or partnership record. Include collaboration responsibilities in staff terms of reference.
- Combined training of selected co-operators and partners to help reconcile differences of approach/philosophy and increase ownership of the project process and outputs.
- Budget includes provision for training in linkage management, telecommunication facilities (radio, fax, e-mail), meetings, workshops, etc.
- Monitoring and evaluation of partnerships and linkages half way through a project, possibly by a second stakeholder analysis. In this case indicators should include resolutions of problems identified at the first stakeholder analysis.
- Collaboration issues should be addressed in project reviews.

BUILDING AND MANAGING FARMER CAPACITY FOR PARTICIPATION

This section deals briefly with the question of institutionalizing the research capacity of farmers. Farmers have been doing their own research for many years, and will continue to do so, with or without support from funded agencies. What then is meant by building or institutionalizing farmers' research capacity? The idea here is that through project inputs, organizational arrangements can be established to facilitate better interaction between researchers and farmers. In a number of projects, farmer research groups have been effectively used to perform these functions (e.g. Heinrich, 1993). Groups formed may be empowering, but the main aim is to enliven and sustain the interflow of transactions (mainly information exchange) between researchers and farmers, and also the intraflow between farmers themselves.

From the point of view of pragmatic research efficiency, and not wasting farmers' time, farmer research groups do not need to be 'sustainable', but need only exist as long as they are performing a useful function in the research process – useful, that is, to both farmers and researchers. However, because formation of effective groups can be resource intensive, higher returns to establishment may be achieved if the groups facilitate dialogue between formal sector researchers and farmers on a semi-permanent basis. A few tips for those wanting to try and establish farmer research groups are given in Box 12.

MANAGING INNOVATION AND ATTITUDE CHANGE

Should institutionalization of participatory research in the NR sector focus on individuals or institutions? There is not a simple answer to this question. Institutions may be more or less open to new ideas. Over time, managers of institutions change, and projects come and go. Staff who are receptive to new ideas, may also be more likely to progress within the organization, or to move out of it to take another job. For these reasons, it is important to target both management and the professionals within an organization. A commitment from management for support of participatory approaches is extremely helpful when implementing a participatory research project. Management support for an idea, however, does not ensure that the staff of the organization will implement it. Firstly, they must believe in the idea, secondly, they need a clear understanding of how to put the idea into practice, and thirdly, they require the resources to make the idea a reality.

In the projects described, the first two conditions are most critical because usually these projects have received adequate resources (in terms of transport, operational budget, communications, etc.). At the least, these projects have had a team leader, or senior team member, with a belief in the value of participatory research and

Box 12 Tips for starting and managing farmer research groups

Starting groups

- Study the past history of farmer group formation and existing group structure and norms.
- Select representative villages/communities with reference to zonation.
- Evaluate existing groups and select ones with potential.
- Conduct awareness raising through PRA, public relations activities, technology marketing, and participatory planning.
- In the above, define the image of outsiders through clear presentations.
- Provide guide-lines for farmer research groups composition/establishment (e.g. secret ballot for electing group leaders).
- Use well-established farmer research groups to help establish new farmer research groups in other areas.

Managing the working relationship

- Monitor representativeness of group members.
- Provide training for transformation to empower groups and researchers.
- Conduct regular reviews of research priorities/results.
- Support village information systems – linking farmer groups.
- Stimulate farmer to farmer in-season visits.
- Experiential learning by researchers in linking with farmer groups.
- Establish co-ordinated information management mechanism on the research side to reduce conflicting images and messages being presented to farmer research groups by different researchers.
- Discuss processes (biological and ecological) as well as products with farmers.
- Discuss ideas of experimentation with farmers.
- Listen, discuss and resolve conflicts arising within the group.
- Work with a limited number of communities/groups and encourage farmers to make group size self-regulating through their own mechanisms.
- Invite representatives from farmer research groups for workshops and ensure a role for the groups in the research planning process.

some knowledge and experience of doing it. Experienced team members have a critical role to play in influencing other members of the team who have little or no experience. It is the enthusiasm and confidence of those expected to take the lead that will influence the others. Even more important is the actual experience of doing participatory research. Many people may be cynical, suspicious or indifferent at the start, but after they have participated and enjoyed it, their attitude can change radically. For this reason it is important that joint activities using participatory methods are begun early in the life of a project, and that these activities are led by researchers who are experienced and confident in using participatory approaches.

It is also important that team members who are new to participatory approaches are encouraged to document and reflect on their experience.

Often technical scientists have difficulty in writing about research activities that fall out of the traditional natural science research paradigm. They are likely to need support, encouragement and even some training in qualitative data analysis and reporting.

CONCLUSION

We have discussed some of the key decision areas arising during the planning and implementation of participatory research projects. Referring to the experience of past projects and drawing on the experience of practitioners involved in implementing these, we have proposed some strategies, tactics and tips for handling some of the key decision areas. There are no doubt other important decision areas we have not covered, one of these being how to develop an exit strategy for a participatory research programme. One thing, above all others, we would like to emphasize is the importance of adopting a team-oriented learning approach to all key decisions. When the key team members are involved in the decision process, and share the attitude that it is more dangerous not to reflect on the consequences of past decisions than it is to make a bad decision, then this is a healthy sign.

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Chapter 3

LOCAL PEOPLE'S KNOWLEDGE: ITS CONTRIBUTION TO NATURAL RESOURCE RESEARCH AND DEVELOPMENT

Hilary Warburton and Adrienne Martin

INTRODUCTION

The generation, transmission and application of knowledge are vital to the development of strategies for sustainable natural resource (NR) management. Changing pressures on NR use, the complexity of agricultural systems and the risks inherent in surviving in fragile ecosystems mean that local people need relevant knowledge and information systems to make informed decisions over NR management.

Advances, for example, in data processing techniques such as geographical information systems (GIS) or genetics, provide opportunities for the application of new technologies to the problems of rural poverty. However, knowledge about natural resources is not the sole preserve of scientists. Farmers have been developing agricultural systems, domesticating animals, breeding new crop varieties, constructing irrigation systems, etc., throughout the centuries without the aid of formalized scientific approaches and agricultural extension systems. Also, the application of new scientific knowledge does not occur in a vacuum but has to be incorporated into a specific context.

In this chapter the importance and relevance of the knowledge systems of local people are discussed in relation to NR research and development. The first section considers what is meant by local knowledge, how it relates to scientific knowledge and some of the theoretical issues in looking at knowledge systems. The second section looks at approaches and methods that can be used to incorporate local knowledge into research and development projects. Lastly, case studies taken from Department for International Development (DFID)-funded projects illustrate aspects of local knowledge related to different natural resources.

APPROACHES TO UNDERSTANDING LOCAL PEOPLE'S KNOWLEDGE

A variety of terms have been used in development literature to refer to the collective knowledge of local people: indigenous knowledge, indigenous technical knowledge, 'traditional' knowledge or rural people's knowledge. The term 'local people's knowledge' (LPK) is used here to include local knowledge of people in both rural, peri-urban and urban communities who use natural resources in some way. Many may be farmers, but those with other occupations, such as pastoralists, foresters, hunters and gatherers, fisherfolk, artisans, food processors and traders, should not be forgotten. Many are likely to be poor, relatively powerless and marginalized. Local knowledge is also held by those in the government and private sectors.

There have been a number of different approaches to looking at LPK and its relationship to development issues. Prior to the 1970s, the study of local knowledge systems tended to be thought of as mainly of academic interest – the preserve of anthropologists and ethnoscientists – rather than of relevance to development specialists. Since then there has been a growing interest in the role of local knowledge in development, initially focusing on indigenous technical knowledge (ITK) and emphasizing the differences between western science and ITK. Over subsequent years the debate on LPK has widened and the emphasis changed from one concerned with technical knowledge *per se* to an emphasis on the processes of knowledge generation itself and the interactions of those involved in development, adoption and diffusion of knowledge.

Transfer of technology approach

In the 1950s and 1960s a prevailing view was that scientific research applied to problems of rural poverty would provide the new knowledge needed to transform rural people's lives and improve their welfare. New technologies were generated, then transferred to extension services for dissemination onwards to farmers. The flow of knowledge was one-way, from scientifically trained researchers via extension to farmers. This transfer of technology (TOT) model (Chambers, 1983), implicitly assumed that the source of all useful knowledge lay with scientists, and that rural people had nothing to contribute, their knowledge being inadequate and unscientific (which was the reason why they remained poor) or, at best, irrelevant and only of interest to a few anthropologists. Farmers were regarded as passive recipients of new knowledge and were either adopters or non-adopters of the new technologies. Although the debate on LPK has moved on from this view, in practice, the TOT model continues to exercise a strong hold in many development projects and in research and extension systems.

Criticism of the TOT model was prompted partly by the growing evidence that many development projects were not working well and farmers were not adopting recommendations. Instead of the non-adopting farmer being regarded as inherently conservative or irrational, it was argued that the recommendations and technologies were not always appropriate to the farmer's circumstances (Brokensha *et al.*, 1980, Chambers, 1983). There was also a concern that local knowledge was being displaced by the prestige and arrogance of formal science and therefore, the capacity to produce it would wither away.

Studies of indigenous technical knowledge

These concerns over the TOT model led to an increased interest by those involved in development in looking at the social and economic situation of resource-poor farmers and their knowledge of their own environment and farming systems.

Many studies of ITK have pointed out the richness and depth of local people's knowledge (for example, Brokensha *et al.*, 1980; IDS 1979). Instead of farmers learning from scientists, there were many things that scientists could learn from farmers. For example, Hanunoo farmers in the Philippines could identify 400 more varieties of rice than taxonomists (Conklin, 1957, cited in Brokensha *et al.*, 1980); Iko bushmen used observation, touch and smell to distinquish between plant species (Heinz and Maguire, n. d., cited in Brokensha *et al.*, 1980); Kenyan farmers described aspects of the life cycle of variegated grasshoppers of which scientists were unaware (Richards 1980); farmers in East Africa knew there was an association between rainfall and lunar phase, an observation at first denied by scientists then subsequently found to be true after analysing climate data (Reed, 1970, cited in Chambers, 1983). The studies demonstrated that farmers could be keen ecologists, with detailed knowledge of their local environment and observation of natural phenomena over many seasons.

LPK does not only relate to knowledge of the environment and farming systems but also to the active process of innovation. Farmers experiment and develop technologies to fit their own environment (for example, Chambers *et al.*, 1989). Richards (1985) detailed many forms of experimentation and innovation by farmers in Africa. Farmers in Bangladesh showed Brammer (1980) how they had developed horticultural-type methods for growing cereals in areas he thought unsuitable for growing such crops. Farmers in the Andes modified storage for potatoes (Brush, 1980). Experiments may be undertaken as part of normal farming practices and can be divided into those aimed at solving particular problems, those aimed at adapting technologies to local circumstances, and those simply undertaken out of curiosity, to see what happens.

The literature on ITK demonstrated the rationality of rural people's knowledge and its usefulness in inventing and adapting technologies to local conditions. One of the main strengths of ITK was the ability to place technologies in both their social and ecological contexts. It was argued that ITK was a valuable resource and could complement scientific knowledge. As such it should be studied and incorporated into formal research to make development projects more appropriate to local people's needs and more sustainable. Instead of a one-way flow from scientists to rural people, a much more equitable partnership was envisaged between them.

From ITK to a wider perspective on local knowledge systems

Much of the original focus of studies on local knowledge was on technical knowledge. More recently there has been a move amongst development specialists towards a wider definition of local knowledge which includes cultural as well as technical knowledge (Scoones and Thompson, 1994; Bebbington *et al.*, 1993). This move to rural people's knowledge (RPK) from ITK recognizes that local technical knowledge is interlinked with social and political knowledge and skills. (A view closer to the anthropological perspective.)

There has also been increased recognition that LPK is not just a discrete and fixed pool of knowledge belonging to one community. It is a dynamic process. Knowledge is generated and diffused through the interactions of people within specific social and agro-ecological contexts. Within a community there is not one set of accepted knowledge, but many people with differing objectives, interests, perceptions, beliefs and access to information and resources. "Knowledge which is diffuse and fragmentary, emerges as a product of the discontinuous inequitable interactions between these competing actors" (Scoones and Thompson, 1994). This process is sometimes referred to as the 'social construction of knowledge'. It is in the confrontation between different knowledge and social systems that innovation and generation of knowledge occur.

This more complex view of local knowledge focuses not just on what people know, but on how local knowledge is generated, shared and transmitted. It recognizes that knowledge and access to knowledge are not spread evenly though a community, neither are they unchanging. Knowledge systems are not objective, detached and value free, but inextricably linked with the social, political and agro-ecological context in which they arise. This applies as much to western science as to any system of local knowledge.

Issues of power and social relations are, therefore, not irrelevant to local knowledge but are fundamental to it. Instead of just gathering knowledge from local people and incorporating it into development projects, the emphasis is on the active participation and negotiation by local people in knowledge generation and use. Approaches such as participatory action research (PAR) are used as a means whereby researchers can act as facilitators in encouraging local learning and action.

Knowledge is much more than a collection of facts: it relates to the whole system of concepts, beliefs and perceptions that people can hold about the world around them. This includes the way people observe and measure what is around them, how they set about solving problems, and how they validate new information. It also includes the process whereby knowledge is generated, stored, applied and transmitted to others.

The main points arising from this can be summarized as follows:

- LPK includes cultural as well as technical knowledge
- LPK is not independent of social and agro-ecological conditions

- LPK depends on the interaction of people, therefore, issues of power and social relations are relevant when looking at LPK
- LPK is a dynamic process, not a fixed pool of knowledge.

Who has knowledge and whose knowledge counts?

One consequence of this view of LPK is that it is important to find out who has knowledge and of what type, and whose knowledge counts within the community.

The depth of knowledge about natural resources amongst local people may vary depending on their familiarity with the resources, the differences in responsibilities and the differences in individual interest and intellect. Brokensha and Riley (1980) provide an example from the Mbeere people of central Kenya:

> "Generally, the best information about the small annual herbs is obtained from older women; herd-boys, being always hungry and also experimental, are experts on the range of wild edible fruits; honey-collectors show the most detailed knowledge of flowering sequences, and indeed know most differential characteristics of their local plants. Yet even within a group, one individual will stand out because of keen powers of observation, prodigious memory, curiosity and intellect."

It has already been noted that knowledge and power are interlinked. Differences in social status can affect perceptions, access to knowledge and, crucially, the importance and credibility attached to what someone knows. Differences in relations of power affect which knowledge system becomes openly accepted. For example, Chambers (1983) argues that it is the linkages between modern scientific knowledge and power that condition those with formal education (teachers, extensionists, health workers) to believe that their knowledge and skills are superior to uneducated rural people. It is the knowledge of the most marginalized people that is likely to be disregarded. Power structures may mean that those who have a more in-depth knowledge may be ignored in favour of those with higher status. For example, landless labourers in South East Asia may know more about non-rice food sources in the paddy than the farmers who own the land; in West Africa, the knowledge of a Fulani herdsman about cattle may be ignored because he is an outsider and not fully integrated into the local community, despite the cattle owner delegating responsibility for looking after the cattle to him. When asking for a farmer who is knowledgeable about cropping systems, the researcher may well be taken to the largest and richest farmer (who has sufficient money to solve any technical problems) rather than to the poorer, more knowledgeable individuals who have to rely on their own ingenuity to solve problems.

Gender differences in knowledge

One area where the differences in knowledge and the effects of power relations can often be seen is differences between men and women's knowledge (Fernandez, 1994). Women's knowledge may differ from men's because of gender-based differences in the division of labour. For example, women may be responsible for certain crops or certain operations, such as post-harvest processing. In addition, differences in power relations between men and women may affect their access to knowledge. For example, women may have less access to formal modes of knowledge transmission, such as formal education or village meetings with agricultural extension officers.

In summarizing the possible differences, Norem *et al.* (1989) argue that women and men may have:

- a different knowledge of similar things
- a different knowledge of different things
- a different way of organizing knowledge
- a different way of preserving and transferring knowledge.

It should always be borne in mind that women and men are not undifferentiated groups. There may well be many groupings within each gender. Such differences could also be applied to other social groups (differentiated by age, status, wealth, etc.).

STATIC VS. DYNAMIC: 'TRADITIONAL' AND 'MODERN' KNOWLEDGE

Local people's knowledge is sometimes referred to as 'traditional' knowledge. If LPK is a dynamic process, the concept of 'traditional' knowledge can be problematic.

In certain societies where there has been little change within the farming system over many years, it may be possible to identify knowledge systems which can be considered 'traditional', i.e. a discrete stock of knowledge generated at some (unspecified) time in the past. However, in most rural areas, the use of the term 'traditional' knowledge to distinquish LPK from western science or 'modern' knowledge is misleading as it tends to imply a static, unchanging system. people adapt to changes in their environment and absorb and assimilate ideas from a variety of diferent sources around them. Rural societies are not completely isolated from western or any other types of knowledge systems and within each society there are multiple sources of innovation (Biggs, 1989). Drawing a line between 'traditional' and 'modern' knowledge is very difficult in practice and care is needed in using these terms.

CHARACTERISTICS OF LOCAL PEOPLE'S KNOWLEDGE

It has been argued that LPK has different characteristics to western science due to differences in subject matter, ways of observing and understanding the world (epistomology) and the local context.

LPK tends to be based on observation and detailed knowledge of the local environment over time. It is shaped by the ecological system in which it is located, so is specific to that area, whereas western science tends to generate knowledge with more universal application. Farmers take a more holistic approach to knowledge and problem solving rather than the reductionist approach of western science. For example, a farmer may look at the overall health of the plant, whereas a plant pathologist focuses only on specific disease pathogens. NR-related problems are not just 'technical' problems but part of rural peoples' overall social world with implications for food security, incomes, labour use and relationships with family, kin and neighbours.

Strengths of LPK lie in local people's ability to observe events over a sustained period of time and focus on what directly affects their lives. Many societies using low external inputs tend to adapt to their environment, rather than trying to control it. This gives them an intimate knowledge and understanding of their own environment. Such adaptation to the environment may also be more compatible with conservation. Farmers often have detailed knowledge of aspects such as micro-climates and details of observable phenomena such as plant growth stages and plant associations, seasons and location.

Methods of experimentation may differ with local people relying more on observation, experience and trial and error. Their methods may not be systematic or analytical compared with scientific methods. However, this is not always the case. Richards (1994) provides an example of farmers using sound empirical methodology in evaluating rice germplasm; Fairhead and Leach (1994) argue that rural people do theorize about agro-ecosystem processes. On the other hand, there are also cases where scientific knowledge is not applied in an objective way and where many advances are made on the basis of trial and error and good luck.

Comparisons between knowledge systems

Although such differences can be identified between LPK and western science, drawing a clear line between the two systems is difficult. Authors such as Agrawal (1997) argue that such a dichotomy is misleading. There is great diversity within knowledge systems, whether labelled as 'indigenous' or 'western', 'local' or 'scientific'. The knowledge systems of Bolivian campesinos may vary considerably from those of Somali pastoralists. In addition, many types of knowledge coexist within the community, for example, western scientific ideas exist together with many forms of local knowledge. Rather than perceiving LPK and western science as opposites, it is better to be aware of the possible multiple domains and types of knowledge and to look for the differences and similarities between each type. Norgaard (1988) argues that all knowledge systems, including western science, are embedded in their own cultural settings and, as such, all systems are relative.

Comparisons between LPK and science are, therefore, comparisons between different knowledge systems, rather than an evaluation of LPK against the absolute, objective standard of western science. This does not mean that comparing local perceptions and beliefs with scientific research is invalid or useless. Such comparisons (which are often undertaken in studies of LPK) can be extremely useful. However, simply labelling any LPK that does not conform with scientific research as 'wrong' without trying to understand why the differences arose is unlikely to be helpful in developing useful research that can build on what people already know.

Differences in concepts, classification and language

When studying LPK, researchers need to be aware that local people may use very different concepts to them in understanding natural phenomena, and in their classification systems and the language they use to express these.

In western science the key concepts of natural resources and agricultural systems contain a number of commonly used related concepts to aid further understanding, such as soil fertility, disease, natural enemies and plant resistance. It should not be assumed that any of these necessarily relate directly to equivalent concepts of local people who may have their own concepts and terms to understand and describe the world around them, for example, concepts of soil softening and warming (Fairhead, 1992). Research and extension messages based on scientific explanations are likely to be reinterpreted by local people in the light of their own concepts. Local ideas of cause and effect may vary from place to place, for example, in some communities, incorporating moral or supernatural causal agents in addition to natural phenomena.

Local classification systems may vary both in the characteristics used to classify and in the detail and depth of classification. In some cases the classification relates closely to the practical use. For example, soil types may be classified by the use that can be made of them such as, 'good for yam', 'good for cassava', rather than the soil structure and nutrient content. Bentley (1992) observes that farmers tend to have more detailed and in-depth classifications and knowledge about important and visible phenomena, but limited knowledge of things which are considered to be unimportant or are difficult to observe (Figure 1).

Local classification systems vary in the extent to which they are widely used or specific to a particular district, village or sub-group and in the degree to which classifications and explanations are consistent or diverge. Local names may be very specific to location. For example, the word, *osa,* is used in certain villages in Ghana to mean specific types of caterpillar only; in other villages where the same

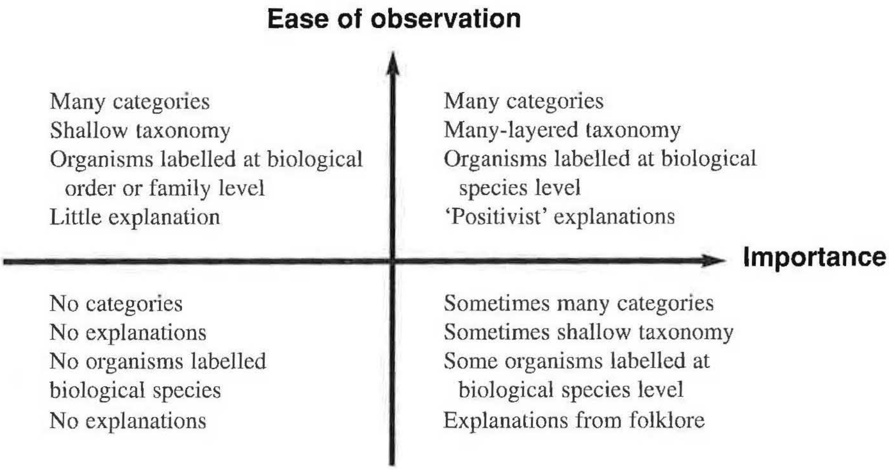

Figure 1 Characteristics of four classes of farmer knowledge (from Bentley, 1992).

local language (*Twi*) is spoken, *osa* has a more general meaning including stemborers and other larvae (Sarfo-Mensah, personal communication).

The language to describe local concepts and classifications often has no direct translation into English or other languages. The complex task of interpreting categories expressed in local languages is well illustrated by examples from a project investigating local knowledge of soils in Tanzania and Uganda. When farmers were asked about their different 'soil types', a long list of categories was produced. However, on closer discussion it became clear that this contained local terms describing land in multiple senses, including terms referring to land use, for example, cultivatable and non-cultivatable land, plots growing food or cash crops, grazing areas, open spaces, etc., as well as physical descriptions of the soils. Categories overlap and coexist rather than being exclusive and their boundaries are blurred rather than fixed and definite, for example, three different terms were given for 'sandy' soils in a village in Katakwi district of Uganda. These were loosely distinguished by different sand grain size, colour, fertility, subsoil, but all were more or less sandy.

LIMITATIONS OF LOCAL PEOPLE'S KNOWLEDGE

In highlighting the strengths of LPK, it is important not to over-romanticize it. Farmers know a lot, but not everything. Chambers (1983) notes that farmers may know much about agricultural cropping systems but their beliefs on health may may be wrong or even dangerous. Bentley (1992) points out that what farmers do not know cannot help them. In his classification of the four types of farmer knowledge (Figure 1), he notes that scientists may well learn from farmers about the important, conspicuous phenomena, but farmers, who lack the means to observe microscopic elements, can learn from scientists about the less easily observed phenomena.

Knowledge of indigenous peoples is important in managing and conserving natural resources, and this has led to a view that such knowledge leads to sustainable practices and reflects a balance of people's needs and nature evolved over time. Although such linkages between environmental conservation, local knowledge and practices of indigenous societies may certainly exist and be of great value, a completely uncritical acceptance of LPK as always synonymous with conservation can be misleading. In the case of tropical forest conservation, for example, Browder (1995) argues that such a view is overstated. Local knowledge systems change over time, and non-indigenous people coming into an area can adapt to new environments and develop local knowledge over time. Also he argues that assuming contemporary indigenous people behave in an ecologically appropriate manner, unlike others, is both hypocritical and culturally insensitive.

WHY IS LOCAL PEOPLE'S KNOWLEDGE IMPORTANT FOR DEVELOPMENT?

Having discussed issues in the study of LPK, its characteristics and limitations, we can identify the following areas in which LPK is important for development:

- an essential first step for any development project
- better innovation and adaptation of technologies to local conditions
- adds to scientific knowledge
- increases understanding between researchers and local people
- increases the local capacity to experiment and innovate
- helps to empower local people.

An essential first step for any development project

As a basic requirement, any project which seeks to introduce new knowledge and new technologies, should find out first what people know. Not to do so is firstly, arrogant and discourteous, and secondly risks the possibility of introducing elements which are known already, or not appropriate. New innovation should build on what people already know and enhance it; it should not ignore what is already there.

Better innovation and adaptation of technologies to local conditions

Local people's knowledge of their own agro-ecological and social environment means that their knowledge can contribute to developing appropriate solutions.

Adds to scientific knowledge

Local people's knowledge may be more extensive or in-depth than that of scientists. There may be much to be learnt, especially about how to survive in harsh and marginal environments. Therefore, knowledge gained from local people can add to knowledge which may be of use elsewhere. In addition, valuable local knowledge can be recorded and preserved.

Increases understanding between researchers and local people

An increased understanding of the farmers' knowledge systems allows a better understanding of the rationale behind the farmers' actions and may allow better communication between both. It can also facilitate information exchange and local people's access to sources of information.

Increases the local capacity to experiment and innovate

In a changing environment, the capacity to innovate to find solutions for new problems is vital. Incorporating LPK into development projects is a means of supporting this by encouraging community self-diagnosis and raising awareness.

Helps to empower local people

More local participation in research and increased respect for local knowledge may help in focusing attention more clearly on the needs and priorities of the poor, and also add to their self-esteem. Instead of their knowledge being considered 'old-fashioned', 'ignorant' or 'irrelevant', such knowledge is respected.

HOW CAN LOCAL PEOPLE'S KNOWLEDGE CONTRIBUTE TO NR RESEARCH AND DEVELOPMENT?

Ways of finding out about and incorporating LPK in NR research and development will depend on the objectives, scope and resources available in the project. Whatever the approach taken, there are a number of key questions that should be considered. These include:

- who knows or needs to know?
- what do they know?
- how is knowledge generated, held, changed and transmitted?
- how does knowledge relate to action?
- how can local knowledge be incorporated and enhanced by the project?

Who knows or needs to know?

It may appear obvious who should be involved in studies of LPK. In many cases the key person will be the farmer, but it should not be assumed that s/he is the only person worth talking to. A useful first step is to identify all the different groups or individuals who use or have some dealings with the subject in question. Two examples from different NR projects (non-timber forest products and weed control) are shown in Box 1. In each case, individual stakeholders may have differing but pertinent knowledge. For example, gatherers may know a lot about where different fruit or other species of plant grow, but little about economic timber trees. In weed control, if women are responsible for weeding, they may know more about types of weeds than the (male) farmer. Labourers may observe more about pests and diseases of the crop if they are in the field every day than a farmer who visits once a week.

What the researcher should try to avoid is talking to individuals about subjects with which they are not familiar and missing those who may have more detailed knowledge. However, it can be difficult involving some of the people identified. There can often be some reluctance, both on the part of the researcher and local people. There may be pressure to ignore certain individuals because they are not educated. Local farmers may prefer to answer for their labourers or family; men often try to answer for women. Farmers themselves may feel embarrassed and reluctant to talk to the researcher.

Box 1 Example stakeholders

Non-timber Forest Products	Weed Control
Farmers	Farmers
Hunters	Women labourers (weeding)
Herbalists	Male labourers (pesticide application)
Fuelwood collectors	Pesticide dealers
Wood carvers	Extension staff
Gatherers (fruit, snails, etc.)	
Loggers	
Wildlife officers	

What do they know?

Researchers should be clear about their objectives here. There is a large difference between (a) finding out whether local people comprehend scientific knowledge and recommendations, and, (b) finding out local people's own understanding of the world around them.

Many studies of farmers' knowledge concentrate on the first objective and effectively set out to assess farmers' knowledge of scientific terms and practices. These can be useful, but they only investigate what the farmer knows in terms of western science and not in terms of his or her own concepts. If the farmer's answer differs from the researcher's knowledge, then it is often assumed s/he is wrong and has no knowledge. However, the farmer may have different knowledge expressed through different terms and concepts.

Finding out about local people's own knowledge requires the researcher to be open to different ways of viewing the world, and not to assume that local people automatically use the same set of concepts as they do. Main areas where there may be differences between local people and researchers include:

- classification and identification of natural phenomena
- concepts of cause and effect
- concepts of NR processes.

How is knowledge generated, held, changed and transmitted?

There are a number of questions that are useful to consider:

- what are people's sources of knowledge?
- who has access to what information?
- who learns from whom?
- what influences/changes existing knowledge?
- how is new knowledge validated?

People are likely to obtain information both from their own observations, experimentation and from many other sources. Mapping out all sources of information and the linkages (theoretical and actual) between such sources and local people can illustrate where the main channels of information are and who has access to them. There is sometimes a tendency for researchers to ignore sources of information outside the formal research–extension linkages, but sources, such as advice from other farmers, need to be considered as well as formal sources. Such local, informal sources may well be held in higher regard than that from outsiders who are not 'real' farmers. Commercial sources, for example, agrochemical dealers or traders, can also be very important and influential. Information via the media can add to farmers' knowledge. Ideas on nutrition, health, the environment may be incorporated into ideas about agriculture and natural resources.

Validation and acceptance of new knowledge is important, especially in assessing how new ideas are taken up. Researchers may validate new information by replicated trials and so on. Farmers may not have such a formal method, but may still carry out their own experiments. Widespread acceptance may also depend on the endorsement of certain key people, for example, chiefs or large farmers.

Participatory research is one way of incorporating knowledge generation directly into the project. Rather than the local people being the objects of research, they are actively involved in the process of research (see Chapter 1).

How does knowledge relate to action?

The relationship between knowledge and practice is not straightforward. For example, knowledge that cigarette smoking is harmful does not always lead to giving up cigarettes. The researcher cannot assume that knowledge of something will lead to a change in practice. Conversely, the researcher cannot assume that a practice is not adopted because local people have insufficient knowledge. For changes to occur, people need the relevant knowledge, but also the social and economic ability to change, plus an attitude of wanting to change.

For example, farmers in Ghana were aware of the benefits of soil from rubbish tips on plant growth, but did not use such compost on their farms despite its free availability. The costs of transporting the compost to the farm, and the slow action of the compost were perceived as not worthwhile by farmers who had very short-term access to land. There was also a stigma attached to using dump soil containing untreated waste (Warburton and Sarfo-Mensah, 1998).

How can local knowledge be incorporated and enhanced by the project?

Advantages of incorporating local knowledge into research and development have been outlined above. Practical applications may include:

- changing research priorities and directing research into areas highlighted by LPK
- allowing better adaptation of research to the local environment
- identifying what farmers know and do not know, hence developing appropriate information and extension to fill in knowledge gaps
- enhancing local people's capacity to innovate.

METHODS FOR EXPLORING LOCAL PEOPLE'S KNOWLEDGE

Many methods have been used in eliciting LPK. Choice of method will depend on the objectives, scope and resources of the project and how much is known already. To gain an in-depth understanding of local knowledge systems requires detailed study. Techniques of cognitive anthropology, systematic studies of perceptions and folk taxonomies have all been used (see Brokensha *et al.* (1980) for examples). For the researcher without specialist, anthropological training, rural appraisal approaches can yield considerable insights if used with care. However, it should be borne in mind that short studies, even if well-conducted, are unlikely to produce the same level of understanding as that obtained through sustained, specialist study.

Existing studies

Before starting on any fieldwork, it is worth checking secondary data sources, including those outside the immediate scope of the project. For example, in-depth studies carried out in areas such as perceptions of human health can yield useful insights into how people view their world, and how they consider cause and effect.

Participatory approaches to exploring LPK

Participatory approaches involve local people in working with researchers in assessing their own situation, diagnosing and prioritizing problems and developing solutions. Qualitative research methods are used, such as semi-structured interviews, mapping, diagramming and ranking techniques, to enable local people to describe and discuss their situation. As this involves an emphasis on local people's own knowledge and practices and is situated within the community, use of such an approach can yield many insights into LPK. Qualitative research methods are more flexible than highly structured, quantitative methods such as questionnaire surveys, and can be better suited for finding out what, how and why people think and know about natural resources.

Use of qualitative, 'informal' methods is not a soft option, and requires as much or more skill from the researchers as for structured surveys. Poorly conducted PRAs can produce superficial results or be used to confirm what the researcher already thinks, without investigating in more depth. They also can be subject to interviewer bias, respondent bias and problems in translation in similar ways to structured surveys.

Examples of methods for exploring LPK

Semi-structured interviews

If it is not known what people know, then it is difficult to determine exactly the questions to ask and how to ask them from the outset, as would be required for a structured questionnaire. Semi-structured interviews allow the participants more scope to investigate what people know and to follow up in topics of interest as they arise in the discussion. They can be used with groups and individuals.

Group (focus) interviews

In a group interview, exchanges between participants with differences of opinion can often lead to greater insights into people's perceptions. Thought has to be given to the composition of the group so that as many participants as possible feel free to express their opinions. Those with less status may be hesitant to reveal what they know or to contradict others, and may be better interviewed in a separate group or individually.

Key informant interviews

It may be useful to find out and interview experts (those identified by local people as having specialist knowledge). Take care that such 'experts' do not only include those with formal education and access to scientific knowledge.

Field visits and transects

These are useful in allowing the farmer or informant to point things out *in situ*. Many aspects of agriculture and NR management cannot be described easily in interviews in the village. Also, such visits often provide a more relaxed atmosphere than a group meeting, making communication easier.

Mapping, diagramming, ranking exercises and games

These can be used in many different ways to elicit farmers' perceptions of important characteristics of natural resources, including spatial conceptions, definitions, classifications and boundaries. Examples are listed in Box 2. There is no finite list of techniques. The choice is dependent on the preferences and imagination of researchers and local people. Further ideas can be gained from literature such as *PLA Notes* (IIED).

Box 2 Examples of methods for exploring local knowledge

Participatory mapping of watersheds
Ranking of importance of pests and weeds using traditional board games (Barker, 1980)
Comparing characteristics of different soils using pairwise ranking diagrams
Seasonal calendars of rainfall patterns
Network diagramming of knowledge sources

Structured questionnaires and knowledge tests

Structured questionnaires and knowledge tests have often been used by agricultural extension researchers and others to find out how much local people know. However, such a quantitative approach is not usually a good starting point for studies of LPK, unless the researcher already has an in-depth knowledge of local perceptions and practices. Imposing the rigid structure of a questionnaire implies that the researcher already knows enough about people's perceptions and practices to be able to write specific, unambiguous and comprehensible questions (see Box 3). In practice, these questionnaires may reveal whether the respondents understand scientific terms but provide little information on what the respondents' own ideas might be. Knowledge, Attitude and Practice (KAP) surveys is the name given to these surveys which relate the respondent's knowledge and attitude to their resulting practices. Often the results are scored like a knowledge test. If the respondent's answer differs from scientific knowledge or recommended practice they may be classed as 'wrong' and as having no knowledge.

In general, structured surveys are not good for finding out about what, how and why local people think about natural phenomena and forming hypotheses about LPK. They can, however, have a useful role in following up on, and verifying, hypotheses generated using rural appraisal and other qualitative methods. For example, if it has been found from group interviews that farmers think that certain

Box 3 Example knowledge questions

Example KAP question	Comment
1. When should you apply pesticide in your field?	Complicated question which does not allow for other options.
• when there are a few butterflies in the field ____	Assumes the farmer associates butterflies with caterpillars or other pests.
• when the economic threshold level is reached ____	Assumes the farmer understands the concepts of economic threshold level and natural enemies.
• when there is an equal number of insect pests and natural enemies in your field ____	
2. When should fertilizer be applied to the crop?	Does not allow for other options.
• basal application and during panicle initiation ____	Does not allow for variation depending on the variety, weather conditions, condition of soil, etc.
• 10 days and during panicle initiation ____	Assumes that one answer is correct for all farmers' fields.
• 15–30 days and during panicle initiation ____	

weeds are good indicators of soil fertility, then a carefully worded questionnaire can be used to determine how widespread this knowledge is.

Some practical considerations

Change of attitude

The most important aspect in exploring LPK is not the variety or sophistication of the technique used, but the attitude of the researcher in listening, observing and not imposing their own ideas on those of the local people. This can prove difficult for researchers used to giving recommendations and trained to regard a scientific approach as the only way forward. Keeping an open mind, and recording differences between local people's perceptions and researchers' perceptions, together with the reasons for this, are more useful than simply recording local people's knowledge as 'wrong' or conversely, as always 'right' and 'in tune with nature'.

There is a need to look critically at the researchers' and extensionists' own 'knowledge' as much as that of the farmers.

Power relations

Rural people, especially the poor and marginalized, may be hesitant to explain to richer and more educated researchers what they do and why, preferring to defer to the more powerful and accept recommendations passively without comment. They may regard their own knowledge as so obvious that it does not need to be explained, or that it would be regarded as ignorant or irrelevant.

Problems in concepts and language

Differences in concepts and the language to explain them may hamper communication. Local terms describing natural phenomena may have no direct translation into English. The researcher has to be aware that the full meaning of the concept can easily be lost or distorted when translated. Noting the local name is often useful. Even researchers who speak the local language may find it difficult to translate local terms as they may never have used them in their 'scientific' work.

Context

Observation within the appropriate situation can be important. For example, farmers shown pictures or samples of insect pests in bottles may have great difficulty in recognizing them. This may not be because the farmers do not know the insect, but because the insects are being shown out of their natural context. Farmers (who are not used to looking under microscopes at tiny differences in shape or patterning) may normally distinguish between insects by their location, choice of host, position on the plant, type of flight, etc. A single dead leafhopper in a bottle is very different from several of them fluttering around the leaves of rice plants.

CASE STUDIES

The following case studies are taken from a number of projects funded by DFID. They cover three main areas of NR research: agroforestry, management of pests and diseases and soil fertility. The objectives and approaches varied among the studies, but they illustrate many of the issues discussed above about the contribution of LPK to research and development.

Agroforestry and tree fodder research

(refer to: Thapa *et al.*, 1995, 1997; Thorne *et al.*, 1997, in review; Walker *et al.*, 1997)

A research project on agroforestry and tree fodder was carried out in Nepal, in collaboration with Pakhribas Agricultural Centre; farmers' knowledge was studied as part of the research. The studies demonstrated that:

- farmers had knowledge that scientists did not have
- farmers had specific concepts for NR processes
- farmers had different classification systems.

Background

In the mid-hills of Nepal, agroforestry, crop and livestock production are closely interlinked. Animals provide draught power and manure for crop production and tree fodder provides feed for the livestock. Decreasing common property forest resources and decreasing farm sizes, due to land fragmentation, are causing farmers to incorporate more fodder trees on their farmland. However, farmers need to maintain a balance between providing sufficient high quality tree fodder for their livestock and minimizing the competitive effects of trees on staple food crops (trees compete with crops for light, water and nutrients, and also influence soil erosion through leaf drip effects).

Researchers aimed to improve the effectiveness of fodder research by making it more relevant to the priorities and existing knowledge of farmers and secondly, making more effective use of previous research findings. The specific aims of this research were to investigate and elicit farmers' knowledge of tree–crop interactions and tree fodder, and then record this information in a form which would be useful to other researchers.

Both questionnaire surveys and semi-structured interviews were used. Sixty farmers randomly selected were interviewed and a detailed tree inventory undertaken on half of the farms. Semi-structured interviews were carried out with 40 informants, purposively selected to include differences in gender, ethnicity and altitude of farm. Each informant was interviewed on average four times, with knowledge entered into a database after each interview. A follow-up survey was used to test the representiveness of the knowledge base against the knowledge of 50 other randomly selected farmers. Farmers' descriptions and classification of tree fodders were compared with chemical analyses to see if there was any correlation between the two systems.

In addition, information gained from the farmers was synthesized with scientific knowledge and researchers translated this into a structured knowledge base for wider use. This was done by means of a knowledge-based computer system called the Agroforestry Knowledge Toolkits (Walker *et al.*, 1995).

Results

Tree-crop interactions. Farmers knew over 90 different tree species. They had detailed knowledge of tree–crop interactions, many of which had not been appreciated previously by the researchers. Farmers deliberately managed natural regrowth of trees on crop terrace risers and, therefore, did not need the provision of nursery-grown seedlings or tree planting schemes.

Farmers understood that shade and splash erosion caused by leaf droplets reduced crop yield and had a specific name for the process, *tapkan*. This term has no exact translation and local researchers were unaware of it. Farmers knew that attributes such as leaf size, texture, crown density, size, tree height and leaf inclination angle influenced the shade and/or leaf drip effects and, therefore, they considered tree crown architecture an important factor in choice of tree to integrate into their farming system. This factor had previously been ignored by researchers who had concentrated on such factors as survival rates, above-ground growth rates and total foliage production.

Farmers' understanding of *tapkan* also led to a re-evaluation of the process of soil erosion and resulting crop yield reduction caused by leaf drip. Farmers' assertions that leaf size and texture affected the size of droplets falling from leaves were in contradiction to prevailing scientific literature which held that droplet size was independent of canopy morphology. However, new evidence, using more accurate measurement instruments has found a difference in rainfall drop size under different tree canopies, thus suggesting that farmers' explanations may be valid scientifically.

The depth and spread of root systems were considered by farmers in managing below-ground interactions. Many tree species were classified either as *rukho*, which were thought to exhibit competitive effects which inhibited crop germination and growth, or *malilo* which were thought to contribute to soil fertility through decomposing litter and have less competitive root systems. There had been little research in Nepal on effects of root interactions, but this is one area which farmers consider important but know relatively little about (it is difficult to observe and research root systems) and may have potential for more research.

Fodder classification. Farmers were found to classify tree fodder according to two systems known locally as *posilopan* and *obanopan*. In the first system, fodders are described as *posilo* – nutritious or *kam posilo* – low nutrition. *Posilo* fodders are considered to promote milk production and high butter fat content, rapid live weight gain and animal health and to be palatable. In the second system, fodders are described as *obano* – 'dry and warm' or *chiso* – 'cold and wet'. Farmers consider *obano* fodders to be very palatable, particularly during cold months and associated with animal health, whereas *chiso* fodders were less palatable, and could cause animals to produce watery dung if fed during cold months. Fodders may vary in how they are classified depending on the species of animal to which they are being fed and factors such as season and age of fodder. Farmers assessed the fodder qualities for different trees and were able to differentiate variations in fodder in several, previously undifferentiated species. They also knew how the timing, extent and technique of fodder lopping affected the amount and quality of fodder production from different species.

The farmers' indigenous classification system was compared with laboratory assessments of nutritive value of fodders. These showed that the local classification systems were consistently applied by farmers and that there was some correspondence between local and scientific classifications, for example, between *posilopan* status and protein supply, and between *obano* and overall dry matter digestibility. These relationships were used in constructing a model of feed requirements based on farmers knowledge of the attributes of different fodder species.

Discussion

The research in Nepal not only demonstrated that farmers had detailed knowledge of agroforestry, but the process of research also had an impact on the way researchers thought about research priorities and interactions with farmers. Some of the advantages of this research were that it:

- added to scientists' understanding of tree–crop interactions
- helped scientists reorientate research towards topics of more relevance to farmers
- helped researchers develop a better appreciation of farmers' knowledge
- helped clarify, by recording knowledge in a logical way, what was and was not known and identified information gaps.

Farmers' perceptions of plant diseases

(refer to: Otim-Nape *et al.*, 1997; Warburton, 1994; Warburton *et al.*, in press)

Farmers' perceptions of pests and diseases, that is the identification of pests and plant symptoms, causal agents, relative importance and risks of crop damage, influence the type of plant protection measures they adopt. This case study draws on two research projects which have been looking at ways to develop more sustainable management of plant virus diseases: management of rice tungro virus disease, based in the Philippines, and management of cassava mosaic disease (CMD), based in Uganda.

Results from the two projects demonstrated that:

- farmers' knowledge is uneven
- scientists need to know what farmers know to provide useful help
- knowledge is not static but absorbs new ideas.

Rice tungro in the Philippines

Tungro is a virus disease spread mainly by green leafhoppers (*Nephotettix virescens*). Once a rice plant becomes infected, the leaves become yellow and stunted and the plant eventually dies. Tungro tends to occur in sporadic outbreaks and can cause major crop losses. In the Philippines, the Department of Agriculture in the 1970s and 1980s recommended farmers to spray insecticides to control the leafhopper vectors. More recently, the Department of Agriculture has emphasized non-chemical methods, such as the use of tungro-resistant rice varieties and removal of infected plants.

A collaborative project between the International Rice Research Institute (IRRI) and NRI aimed to research and develop sustainable ways of managing tungro. This included research into farmers' knowledge of tungro to find out whether farmers could recognize tungro and knew what caused it, how they managed the disease, and how their perceptions of tungro might affect their practices. Focused group interviews with farmers in villages which had varying outbreaks of tungro were undertaken first to gain an understanding of the issues surrounding tungro and to explore the reasons behind farmers' perceptions and practices. This was followed by a questionnaire survey of 242 farmers to cover a wider range of farmers.

Results

Farmers' observations of tungro symptoms were similar to those of scientists, but they were much less sure of the causes and mode of spread. About a third said that they did not know how tungro spread. Just over a third thought that insects were involved in spreading tungro but many thought that there were other modes of transmission as well, such as through the air, soil or water. Some thought that the virus was like 'micro-worms' in the plant. Even the farmers who knew that tungro was a virus disease spread by green leafhoppers did not realize the role of diseased plants in providing a source of inoculum for the leafhoppers to spread to other plants. There was no significant difference in knowledge of the disease depending on education, age or gender.

Farmers knew a lot about the differences in susceptibility to tungro of different rice varieties. In tungro-endemic areas, they actively experimented with, and sought out, resistant varieties. However, this observation led some farmers to conclude that tungro must be seed-borne, which is not the case.

Farmers' understanding of tungro and how it is spread did affect the control practices adopted. Spraying insects was a common practice, although this was not always targeted specifically at green leafhoppers. Careful choice of rice varieties thought to be resistant was a common strategy in tungro-endemic areas. However, farmers paid little attention to diseased plants left in the field. Without understanding the risks of leaving such plants, farmers lacked a rationale to adopt measures such as ploughing under infected stubble or leaving fallow periods.

Farmers' knowledge was influenced by information from a variety of sources. Extension messages associated with the drive to rice intensification emphasized the role of insects in damaging crops. Whereas older ideas tended to focus on climatic factors in explaining plant diseases, farmers now are very insect-conscious. Pesticide dealers reinforce the message against insects. Farmers are also 'germ'-conscious. Terms such as 'virus' and 'bacteria' are known to most through the widespread advertisements in the media for drugs. However, the fact that some farmers thought that viruses were like small worms implies that, although the terms are familiar, the way in which they are understood will depend on how they are incorporated into existing notions of plant diseases. Similarities in thinking about plant disease and human disease were expressed by farmers in several ways. The same words were used to describe plant and human sickness (*sakit*). Tungro was described as like AIDS or cancer because it was incurable once the plant was infected.

Cassava mosaic disease

Farmers' knowledge and perceptions of cassava mosaic disease (CMD) provide an interesting comparison to the case of rice tungro. Cassava mosaic disease is caused by gemini viruses which are transmitted by whitefly and spread by using infected stem cuttings for propagation. Although CMD occurs throughout the cassava-growing areas in Africa, its importance in Uganda has drastically increased in recent years, with rapid rates of spread and high levels of severity. As a result of this epidemic, cassava production has been seriously affected and food shortages have occurred in major cassava-producing areas.

NRI has been working with the Ugandan National Agricultural Research Organization since 1991 to develop strategies for CMD control, including the development, multiplication and distribution of resistant material. Surveys of the affected areas were followed by a number of interventions, distribution of virus-free, CMD-tolerant planting material to individuals and groups for multiplication, on-farm trials for farmers to evaluate resistant varieties, and training for extension workers, opinion leaders and farmers on CMD control, improved production methods and rapid multiplication and distribution.

Social scientists focused on farmers practices and knowledge and the socio-economic feasibility of different multiplication and distribution strategies. Methods used were village meetings, meetings with farmers' groups, and interviews with individual farmers, key informants and NGOs, in eleven districts of Uganda. The studies were conducted over several years, so it was possible to trace changes in farmers perceptions and practices, illustrating how farmers knowledge and practice develops and changes over time through observation, practical experience, and interaction with different sources of information. At the same time, because of the unprecedented nature of the epidemic, it was also a learning process for research and extension.

Results

In the early stages of the epidemic, farmers' understanding of the disease differed markedly from those of researchers and extensionists. Farmers' theories and explanations for disease transmission attributed the disease to problems in the soil (e.g. low fertility or soil pests) or to the weakness of 'old' varieties. However, in some regions, farmers theories referred to the moral and supernatural dimensions mentioned above, and associated the destruction of the cassava crop by disease with the socially destructive impact of raiding in their area by a neighbouring ethnic group.

Unlike the tungro case, there was not always a clear recognition of the disease symptoms, which tended to be confused with leaf damage caused by cassava green mite. Farmers were unaware of the role of whiteflies, or the consequences of planting cuttings from infected stems. On the basis of this understanding, the farmers' logical course of action was to open plots on new land where possible, and to try to access different varieties of cassava through informal channels. There was little or no removal of infected plants. In contrast, the extension recommendations were to remove and destroy infected plants, and to replace them with clean planting material and resistant varieties. However, as the epidemic grew in severity, farmers learned that planting infected cuttings produced infected plants, and that cuttings of uninfected (but not resistant) varieties became rapidly infected even when planted in newly opened fields. In the worst affected areas, cassava was almost entirely wiped out. The demand for resistant materials became acute.

Understanding farmers knowledge at different stages of the epidemic was important to guide researchers and extensionists in undertaking practical initiatives to combat the problem and to design effective training programmes for field extensionists and farmers. Examples of early activities were the distribution of tolerant varieties to individual farmers, and group multiplication schemes, initially of tolerant, then of resistant materials. Training for extensionists and farmers was designed to cover existing recommendations, but also included recognition of the disease in the field, observation and explanation of the role of whitefly and training on planting techniques to maximize production of planting material. The research effort to develop resistant materials placed great emphasis on farmers own criteria of assessment of the new varieties tested in on-farm trials.

Researchers also learnt important lessons; it became clear that the introduction of healthy tolerant varieties was only viable where the infection pressure had already been reduced by the disappearance of cassava in the region. Distribution of small quantities of clean material of tolerant varieties was inadequate for CMD control under epidemic conditions. The long-term solution was to develop and distribute CMD-resistant varieties.

The exchange of knowledge between farmers, extensionists and researchers was the foundation for farmer-managed multiplication and distribution of cassava planting materials. With additional knowledge of CMD acquired through training, from extension officers, from informal sources, and as the epidemic progressed, from national media, farmers were able to build on their existing experience of cassava propagation and their own distribution networks. Pre-formed groups with an established structure and leadership were particularly successful and undertook the multiplication and informal distribution of new varieties within their villages and between parishes. Implementation of the control recommendations, particularly sanitation measures, were more closely observed by groups compared to individual farmers' plots.These decentralized multiplication approaches have had an important influence on extensionists (both from government and collaborating NGOs) and researchers by demonstrating the capacity of farmers to manage local cassava multiplication and take decisions on distribution strategies.

Discussion

In both cases, farmers' knowledge was uneven: observation in the field allowed them to develop some effective strategies, such as selection of resistant varieties, without detailed knowledge of the causes of the disease. However, lack of knowledge over the nature of disease transmission meant that farmers put their rice and cassava crops at risk by leaving diseased plants in the field.

There are limits to how much farmers can observe in the field in terms of understanding the microscopic processes of disease transmission. Farmers do not require knowledge of every scientific detail, but scientists should be able to fill gaps in understanding. Scientists need to appreciate what farmers know and what they do not know so they can provide relevant information which will enable farmers to take more informed decisions.

Describing farmers' knowledge as 'traditional' is clearly misleading in these cases. Farmers continually learn from their own experience and experiments and draw on outside sources of information. It is understanding how new information is interpreted, incorporated and used that is important.

Farmers' perceptions of soil fertility

(refer to: Chadwick and Seeley, 1996)

Soil classification can be done in a number of ways based on different criteria, such as underlying rock, soil structure or chemical and organic content. There has been increasing interest in the way in which farmers classify their soils, and whether this is consistent across individuals and communities and is comparable with scientific classifications. In a study in Nepal, farmers' recognition of soil types and their classification was identified and analysed. The study is more than a subjective account of farmers' classification in one area, as it attempts to assess individual and regional differences in classification and also look at how these classifications compare with scientific ones (e.g. USDA soil classification). The study demonstrated that:

- farmers' classification includes practical management considerations
- farmers' classification and terms are not necessarily transferable to other areas.

Background

The main aims of this project were to increase the understanding of Nepalese soils, and specifically, to identify and record intra-regional and inter-regional variations in:

- the types of soil recognized by farmers
- the means by which they are differentiated
- if, and if so how, these diagnostic properties can be quantified
- the relative values placed on the soil types identified in relation to labour requirement, potential productivity, fertilizer requirement and erosion risk
- information on indigenous soil management practices in forest areas
- if feasible, identify the nearest approximation within the USDA soil classification for each soil type identified.

Three forest user groups were selected in different districts of Nepal. A number of different research methods were used, including both soil surveys and rapid rural appraisal (RRA) techniques, such as wealth ranking and focus group discussions. A semi-structured questionnaire was used for interviewing 87 household respondents about soils on their lands and soil–tree and soil–crop interactions. Respondents also ranked soils according to their labour requirements, potential productivity, fertilizer requirements and ease of erosion. Samples of soils identified by farmers were collected and analysed.

Results

Farmers in the three different areas had detailed knowledge of the soils in their area – in one area identifying up to 24 types. Farmers named the soils based on characteristics of the soil 'in the plough' (i.e. the upper horizon) and had a limited knowledge of the characteristics of the subsoil or layers below the plough layer. The indigenous classification, therefore, could not be linked directly to soil classifications such as the USDA soil classification.

Colour and texture were the main factors in classifying soils, but also management characteristics were used. There was agreement between respondents from different areas over the key criteria that determine each of the soil types and there was generally good agreement over the ranking of soils with respect to labour, production, fertilizer and erosion characteristics.

Farmers had a detailed understanding of soil–tree relationships for the main species used on their land and provided information on which soils were suited to different species, but opinions often differed between farmers. These differences were not related to differences in socio-economic characteristics, such as gender, age or wealth rank, but may have been more related to experience in different forest areas.

Results from soil analyses indicated that within each area, the different soil types did have a number of significantly different soil characteristics associated with them. For example, *kalo* and *kalo balaute* soils had higher levels of organic carbon than other soils in one village; *rato mato* soils had lower levels of phosphorus than all other soils except one; *balaute* soils had significantly higher sand percentage than other soils without *balaute* in their name.

When comparing soil types common to all areas, it was found that these also corresponded to some (but not all) similarities in soil variables, for example, *chimtaylo mato* soils had mean clay content which was not significantly different (but differed in other variables); *kalo mato* soils had similar organic carbon contents that did not differ significantly. Greater differences between the same soil type and its corresponding soil variables were found between the two hill communities. One notable result was that *balaute* soils had a significantly different sand content when compared across villages. This indicates that the determination of a *balaute* soil is relative, i.e. it is sandiest soil in the area, not necessarily a sandy soil.

Discussion

The study illustrates that farmers do have detailed knowledge of soils, and some of this is related to practical considerations of differences in management practices. However, the study also indicates that care is needed in understanding and translating from farmers' classifications to scientific classifications. Although farmers use similar criteria in assessing soil types, the results suggest that the values used are relative, not absolute. The typology used by farmers is, therefore, localized in some respects and cannot be translated directly from one area to another.

CONCLUSION

This chapter has tried to demonstrate that LPK has a vital role in NR research and development. However, such knowledge cannot be immediately picked up and used by researchers, independent of the situation in which it was generated. Understanding LPK requires that researchers are aware of possible differences and complexities in how people view the world around them, and in how they interact with each other.

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Chapter 4

DECISION TOOLS FOR MANAGING MIGRANT INSECT PESTS

Mike R.Tucker and Johnson Holt

INTRODUCTION

Environmentally sensitive integrated pest management (IPM) aims to minimize the use of pesticides which are damaging to the environment and to human health. This can be achieved both by the use of alternative methods, such as resistant varieties of crops, modified planting dates, microbial agents and biological control, and by improving the targeting of those chemical pesticides that are used. These approaches require more information than traditional pest control methods. They also benefit from participatory research to investigate how farmers and other IPM practitioners make decisions and what information they require (see Chapter 1). Such information might include seasonal climatic outlooks (see Chapter 10) which can help plan crop planting, suggest when to start monitoring for pests and also the pest population threshold(s) that should be used to trigger control measures.

For ease of implementation, pest management recommendations should be simple but based, wherever possible, on the scientific analysis of information on the biology, population dynamics, economic damage and current and future distribution of the insect pest population (see, for example, Norton and Mumford, 1993). Information on insect populations can be obtained from monitoring actual populations and from the factors influencing their development, such as weather and vegetation growth.

Forecasts may be made by an individual grower for a pest in a particular crop, or by a centralized pest control agency for an entire region. Region-wide forecasting has been implemented for a number of migrant insect pests and has, in some cases, begun to utilize simulation models of pest population processes, development rates, mortality and migration to estimate the future size and distribution of the population (see, for example, Woiwod and Harrington, 1994). Decisions can then be made to target pest control measures so that they are used *only* where and when they are likely to prevent current or future economically significant crop damage, thus reducing costs and potential environmental damage.

For insects pests that move very little (such as many pests of perennial tree crops) or those where a small immigrant population requires several generations to reach pest status (as with many aphids and planthoppers), on-farm monitoring can be used to determine an action threshold for control measures (Tatchell, 1990; Holt *et al.*, 1996). This threshold occurs when pest numbers, determined by sampling within the crop or by light or pheromone traps of flying adults, reach those numbers which, it has been calculated, will result in economically significant damage (Norton and Mumford, 1993). Control based on thresholds within the crop to be protected has been termed *defensive control* (Pedgley, 1993). This method can, however, be for controlling those migrant insect pests, such as armyworm and locust, which often appear suddenly as significant outbreaks in areas where no insects were previously present. Timely forecasting of the arrival of such pests and the use of preventative control measures are key strategies in migrant pest control.

MANAGEMENT STRATEGIES FOR MIGRATORY INSECT PESTS

Migrant pest forecasting

Migrant insect pests, such as armyworms, locusts, some aphids and planthoppers, are those which, for part of their adult life, inhibit their reproductive behaviour and sometimes, feeding, to concentrate resources on migratory flight. By these means they are able to travel long distances and colonize new habitats. Their distribution is, therefore, variable in space and time and can occur within a large area. Monitoring and forecasting of these pests need to be carried out on a national or international basis to take long-distance insect migrations into account. A central organization is generally needed to co-ordinate the monitoring network, make forecasts based on the size and likely movements of the pest populations and disseminate reliable and timely information to where pest management decisions need to be made. Techniques for quantifying insect migration are described by Reynolds *et al.* (1997).

Preventive control

Where insect populations in one place can give rise to far more serious damaging outbreaks in subsequent generations, *preventive (or strategic) control* of initial populations to prevent subsequent outbreaks may be the best option, even when the controlled outbreak is not in itself of economic importance (Pedgley, 1993). Successful examples include control of the African migratory locust (*Locusta migratoria*) and the red locust (*Nomadacris septemfasciata*) in their well-defined upsurge areas in west and south-central Africa, and probably, in some years, of the desert locust (*Schistocerca gregaria*), which has less well-defined upsurge areas in its huge subtropical desert recession area (Pedgley, 1981). Destroying initial gregarizing populations in desert areas, to prevent the spread of populations to agricultural zones, is the basis of the current desert locust control strategy, although there is some dispute over when to initiate control because the role of non-swarming populations is not fully understood (Magor, 1992).

The Desert Locust Control Organization for Eastern Africa (DLCO-EA) has used a similar regional strategic control philosophy against caterpillars of the African armyworm (*Spodoptera exempta*), a migratory moth and serious pest of cereal crops and rangeland, based on research carried out in eastern Africa over a number of years (Rose *et al.*, 1995). In some years infested areas may cover several million hectares with up to 30% cereal loss in outbreak areas (Scott, 1991). Cheke and Tucker (1995) evaluated the potential economic returns of strategic control. Their results indicated that a combination of well-targeted chemical control measures in the areas where 'primary' armyworm outbreaks (those derived from low-density populations) occur, together with timely defensive control in areas of high agricultural productivity, is likely to give best economic returns. Forecasting the location of 'primary' outbreaks has, therefore, been given a high priority and methods aimed at achieving this are discussed below.

Importance of weather

In forecasting the occurrence of windborne migratory insect pests information on weather is vital. Large-scale weather patterns, especially winds, must be taken into account because migrating insects typically fly at a height where their displacement is largely controlled by wind direction and speed and is, therefore, in a downwind direction (Pedgley, 1993). For both migratory and non-migratory insects, development rates are strongly affected by air temperature and this needs to be known in order to predict when migration will take place and when damaging populations are likely to appear. Atmospheric humidity has a significant effect on insect survival. Migration itself is also affected by air temperature, humidity, rainfall distribution. The subsequent success of the migrants depends on the suitability of both wild and cultivated plant hosts for egg-laying and larval development. With improved knowledge of how these factors affect insect populations, together with better monitoring techniques, such as the widespread use of pheromone traps and the rapid availability of information on weather and vegetation from satellites, considerable potential exists for the development of computerized information systems and models to improve forecasts.

Seasonal forecasts

In addition to medium-range *pest forecasts* designed to help target control measures, it is possible to produce seasonal pest outlooks, based on long-range predictions from global climate models and relationships between insect pests and weather. Although seasonal climate predictions are still tentative and the relationships between individual insect species and climate are only partly understood, even very generalized predictions of seasonal weather can be used to help plan crop protection strategies. This will be discussed later in relation to the African armyworm.

The following examples show how new techniques are being used to provide better decision tools for forecasters, who in turn will provide the information on which pest management decisions will be made.

DECISION TOOLS FOR FORECASTING DESERT LOCUST

The desert locust is the best-known and most feared of migratory insect pests; it is capable of sudden appearance and of causing devastation to crops. It inhabits a huge recession area which includes the subtropical deserts of North Africa, the Middle East and southern Asia as far east as north-west India. In plagues, swarming populations can spread beyond the desert areas to the Mediterranean coasts of North Africa and into the seasonally dry equatorial areas of East Africa. Forecasting is, therefore, an international problem and, since 1979, has been carried out by the Food and Agriculture Organization of the United Nations (FAO) in Rome. Magor (1992) summarizes the history of desert locust forecasting and the techniques used by the FAO Desert Locust Information Service, many of which are based on the large body of historical information documented by Pedgley (1981).

Regional forecasting

FAO receives locust and environmental data from national and regional organizations. The locust data comprise reports of surveys by national locust units and sightings by farmers, nomads and extension officers. The environmental data consist of daily synoptic weather charts and rainfall data from meteorological departments and satellite remote-sensing imagery from various regional centres and from the FAO Africa Real Time Environmental Monitoring Information System (ARTEMIS) (Cressman, 1997). Remote-sensing imagery for monitoring locust habitats consists of infra-red imagery from the Meteosat satellite which can be processed to indicate areas of rainfall occurrence and NOAA satellite imagery (visible and near-infra-red) processed to give indices of vegetation greenness, such as the normalized difference vegetation index (NDVI). These data are low-resolution (optimum 4 km for Meteosat and 1 km for NOAA) but of high temporal frequency (half-hourly for Meteosat and twice daily for NOAA). High resolution (about 30 m) but low frequency (about 15 days) imagery from the Landsat satellite has been used together with ground surveys to calibrate NOAA data for a key desert locust upsurge area in the Tamesna region of Niger (Cherlet and Gregorio, 1993) and airborne digital photography has been similarly used on the Eritrean coast (Flasse and Copley, 1997). These studies demonstrated some of the problems interpreting NOAA vegetation indices in areas of sparse vegetation cover.

Following the 1986–89 desert locust plague, FAO identified a need for a computer geographical information system (GIS) for administration, mapping and analysis of locust and environmental data for operational forecasting. This GIS, known as SWARMS (*Schistocerca* WARning Management System), was developed by the University of Edinburgh in collaboration with the Natural Resources Institute (NRI) and FAO. Desert locust distribution maps for 1929 onwards were digitized from hard copy maps held at NRI. In the GIS, current locust information can be mapped and compared with past locust distributions, current weather, climatology and with other environmental data, including topographic and soil maps

(Cressman, 1997). The GIS uses ARCINFO software on a UNIX-based SUN workstation. Models can be used to forecast locust development rate from temperature data and downwind swarm movements from wind and temperature data. In conjunction with the satellite data mentioned above, the system greatly facilitates the analysis of large quantities of data for the production of *Desert Locust Summaries and Forecasts.*

National forecasting

As well as regional co-ordination, national locust early warning systems are well-established in many countries. In Eritrea, for example, the Crop Production and Protection Division of the Ministry of Agriculture in Asmara routinely collects information about locusts and their environment. They pass the data to FAO every month where they are aggregated into a regional picture and used in forecasts. The Red Sea coast is a pivotal recession and winter breeding area from which desert locust outbreaks frequently occur. Timely environmental information is a vital prerequisite of a management and forecasting system, since locust dynamics are intimately linked with vegetation status and both are affected by weather events. Similarly, detailed information covering the locust sitings is needed, including locust behaviour, appearance, numbers and breeding.

A project known as RAMSES (Reconnaissance and Management System of the Environment of Schistocerca), is addressing national forecasting needs on the Red Sea coasts of Eritrea (RAMSES Annual Technical Report, 1997; A. Mills, personal communication). The purpose of this project is to develop a system for acquisition, management and dissemination of locust information and habitat, including calibrating environmental and habitat information with survey data, compiling and validating forecasting analogues for the region and designing an operational data management and dissemination system. The operational system is called the Eritrean Locust Management and Analysis Tool (ELMAT).

An example: the Eritrean Locust Management and Analysis Tool

The ELMAT system combines data from many different sources and of different types. Locust siting information is gathered by formal surveys by locust experts, or informal reporting by truck drivers, nomads or farmers. The quality of these data is highly variable and sometimes of questionable accuracy. The database is structured to allow users to both enter and access a quality assessment of this information. Environmental information also comes from various sources including locust or other surveys and may include meteorological, vegetation, soils, geology and geomorphological data. Data from rainfall stations have been mapped for the region so that rainfall data by dekad or month can be shown either as a map or a chart for a selected year. Finally, the system allows the storage of satellite image products, such as NDVI, that can be displayed showing the relevant thresholds for the Red Sea coastal plain for vegetation greenness (as calibrated during fieldwork). A series of default map layers are used within the system, but the user has the ability to store other maps in the system (e.g. land use maps, surveys, etc.) and reference them into the GIS through a metadatabase. ELMAT also allows users to create their own data layers intended for simple interpretation, summary layers or annotation to maps.

The locust and rainfall information, and the map and satellite metadatabases are stored in MS Access software, utilizing its form structures and programming functionality. The satellite data are stored in a standard image format converted at source by the Eritrean Meteorological Department at Asmara airport. The topographical data are in ARCINFO format.

ELMAT is not intended to be a forecasting tool in itself, but allows users to assimilate the relevant information geographically so that they can use their expertise to monitor the locust situation and environment. ELMAT allows the user to query the locust database and shows all the locust sitings for a selected month throughout the region affecting Eritrea or to look at a series of months or a sequence of years for the same month (e.g. a series of January's from 1989 to 1995), to compare the current situation with past events. Certain key events have been visualized in a series of maps interpreting the changing locust situations (both in terms of migrations and population development) through a series of searchable case studies, fully supported by a bibliography of sources. The keystones of the system are the ability to overlay locust, environmental and other data of a similar time period (i.e. monthly) on the same map to aid forecasting, and to look at analogies from the large historical database. It does rely, though, on timely acquisition of rainfall, satellite and locust data and careful registration of data within the system.

DECISION TOOLS FOR FORECASTING AFRICAN ARMYWORM

It has been known for many years that African armyworm moths are migratory and plotting the changing distribution of outbreaks and trap catches in relation to winds and rainfall has, since 1969, been the basis of armyworm forecasting by national forecasting units and by the DLCO-EA (Brown *et al.*, 1969; Odiyo, 1990). Research using entomological radar demonstrated that armyworm moths fly downwind following emergence and can be concentrated by convergent winds associated with rainstorms (Pedgley *et al.*, 1982; Riley *et al.*, 1983; Rose *et al.*, 1985). When armyworm moths land they are likely to breed. The hatching larvae benefit from the flush of green vegetation resulting from the rain and can give rise to high density outbreaks.

Local knowledge in Africa has considered that severe African armyworm outbreaks occur when rainstorms follow droughts (Brown, 1962) and this has been confirmed in a number of studies. Tucker (1984) found an inverse correlation between numbers of armyworm outbreaks in eastern Africa and October to December rains at the beginning of the season. An inverse correlation between light trap catches of armyworm moths in Tanzania and November rainfall in central Tanzania was found by Harvey and Mallya (1995) and Haggis (1996) also found an inverse correlation with the previous long rains (April–May). Haggis developed some decision rules for forecasting the coming armyworm season starting with a provisional forecast in June and ending with a confirmed forecast after the following October. Climatological research has found that heavy October to December rains in eastern Africa are often associated with El Niño years when the strong warming of the eastern Pacific ocean leads to climatic anomalies around the world (Nicholson and Kim, 1997). As El Niño years are usually well-defined by June, their occurrence can be used as a provisional forecast of a low armyworm year.

In 1991 a computer database, known as 'WORMBASE' was developed to incorporate both historical and current armyworm data, in the form of outbreak reports, light and pheromone trap catches and rainfall data (Knight and Day, 1993; Day *et al.*, 1996). It facilitates forecasting by enabling distribution maps to be printed and plots of trap catches to be compared between stations and between armyworm seasons. It also contains models of armyworm development rate for different locations, based on temperature and elevation (Pedgley *et al.*, 1989; Robinson, 1991). As with locust forecasting, trajectory analysis, based on daily windfields, has been used to estimate downwind migration of African armyworm (Tucker *et al.*, 1982; Tucker, 1994) but is not incorporated in WORMBASE. WORMBASE is being used routinely by the Armyworm Forecasting Unit in Arusha, Tanzania.

WORMBASE in use

The decision process in current use by forecasters in Tanzania is summarized in Table 1. To simplify the decision process to its essential features, the factors have been presented as having yes/no options but in fact a continuum of responses is possible. 'High moth catch' has a site-specific definition and the historical records for a particular trap are used to indicate whether a given catch is high for that trap. The existence of current storms or wet ground are considered as being of equivalent significance. Although current storms are clearly important for moth convergence, a high trap catch is itself taken as evidence of a sufficient concentration of moths to produce an outbreak. A high moth catch and local emergence of moths from a previous outbreak site are also given equal significance. For example, it may be known from information gained earlier in the season, that an emergence is due, even when trap information is unavailable.

The six situations presented in Table 1 encompass all possible scenarios. In situation 1, historical records play no part because conditions are known to favour outbreaks. In the absence of current or previous rainfall information, the prognosis depends on historical records. The outbreak risk is considered high if outbreaks are common historically in that district and month (situation 2) but medium to low if outbreaks are not common historically (situation 4). Where it is known that rain has not fallen, currently or recently, then the outbreak risk is low even if the moth

Table 1 Summary of decision criteria leading to an outbreak risk assessment for armyworm in Tanzania

	Possible situations					
Factor to consider	**1**	**2**	**3**	**4**	**5**	**6**
High moth catch or emergence of moths from previous outbreak	✔	✔	?	✔	✔	?
Rainstorms or ground already wet	✔	?	●	?	✘	●
Outbreak historically likely in the month and the district	●	✔	✔	✘	●	✘
Outbreak risk prognosis	**H**	**H**	**M**	**M/L**	**L**	**L**

✔	Yes
✘	No
?	Unknown
●	Yes, no or unknown
H, M, M/L, L	Forecast of outbreak risk high, medium, medium to low and low, respectively.

Source: After Mr W. Mushobozi, personal communication.

catch is high and irrespective of historical data (situation 5). Where no moth catch data or emergence data are available, then the prognosis depends on historical records not rainfall information, and outbreak risk is considered either medium (situation 3) or low (situation 6).

Use of remote sensing

In 1988, a PC-based Meteosat receiving station was installed at DLCO-EA, Nairobi, to aid armyworm forecasting by locating night-time rainstorms from infra-red images. A significant association has been found between rainstorms following dry periods early in the armyworm season (October to December in East Africa) and the occurrence of 'primary' outbreaks (Tucker, 1997). Rainstorms are identified by the temperature of the cloud tops as measured in the Meteosat infra-red channel. The software calculates a 'cold-cloud duration' (CCD) image by adding the number of hours that a cloud-top temperature lower than a fixed threshold of -50 °C is present for each pixel (data point). For armyworm forecasting, daily (or nightly) CCDs are calculated to identify the presence of individual rainstorms that might be associated with moth concentration leading to armyworm outbreaks. However, when rainstorms are widespread over several weeks, rain and high humidity are likely to result in drowning of young larvae and increased disease leading to high overall armyworm mortality. The technique is currently being used at NRI to provide summaries of information which are sent by e-mail to the Tanzania Armyworm Forecasting Unit at Pest Control Services, Arusha. Results are summarized for a grid of degree squares (1° latitude x 1° longitude) for each day.

A model to forecast African armyworm outbreaks

A series of rules to interpret armyworm trap catch information was developed by Odiyo (1990). Holt and Day (1993) and Kirenga (1991) developed rule-based models of armyworm population dynamics. Here the model described by Holt and Day is expanded to incorporate moth migration and satellite-based weather information. Rule-based modelling is a new approach which differs from current forecasting practice for either African armyworm or desert locust. It is the qualitative equivalent of the conventional quantitative simulation model. The rule-based approach enables subjective knowledge about a system to be used to build models by representing components by a small set of distinct states and changes by logical 'if-then' type rules. Starfield and Bleloch (1986) and Holt and Cheke (1997) discuss the application of rule-based models to wildlife management and agricultural entomology, respectively.

The key assumptions that are incorporated in the African armyworm rule-based model can be summarized as follows:

- armyworm moth arrival prior to oviposition is often associated with rainstorms
- armyworm larval survival is enhanced by the growth of young grass following rain, but especially after a drought period
- mortality of young larvae is increased by heavy rain after hatching
- mortality of all larvae is increased by continuous rains due to the build-up of pathogens such as fungi
- newly emerged armyworm moths migrate downwind
- in the absence of current synoptic wind data movement, directions can be estimated by using frequencies of dominant wind directions for the month
- the likelihood of rainstorms occurring in a particular degree square on a particular day can be estimated from Meteosat CCD images.

There are two distinct processes in the life history of the African armyworm which must be modelled effectively: migration and breeding. Adult moths can migrate up to several hundred kilometres from their emergence site and cause new outbreaks of larvae when the moths are reconcentrated and deposited by convergent wind-flow, usually in the vicinity of storms. Thus, outbreaks of larvae may, or may not, lead to further outbreaks depending on a number of interacting biological and meteorological variables. Breeding occurs once the adults have landed: mating, egg-laying and larval development take place at the site where the moths land. An outbreak of larvae occurs if the parent moths are sufficiently concentrated and arrived in sufficiently large numbers. The next generation of adults usually leaves that particular locality but a second generation can occur at the same site if conditions are suitable.

The model is intended to provide a general picture of the potential future progress of the 'armyworm season'. To this end, a large spatial unit is chosen as the basis for simulation, i.e. the degree square. The choice of large spatial unit also keeps the data required to run the model to manageable proportions. Inferences are made about armyworm population processes within that degree square as a whole. Thus, processes such as emigration relate to the degree square, not to the outbreak site; for example, an emigration rate of 95% means that 95% of moths emerging within the degree square leave the degree square.

The simulation proceeds in weekly steps. This is probably the largest step that allows the important interactions between biological and meteorological variables to be represented sensibly. With a weekly time-step, armyworm life history can be divided conveniently into five stages, each of 1-week duration: adults *A*, small larvae *LS*, large larvae *LL*, prepupae *PP*, and pupae *P*. Note that the 'adult' stage includes the period from pupal emergence to egg hatch. A 5-week life cycle is appropriate for a large area of central and western Tanzania in the altitude range 750–1200 m. At lower altitudes, nearer the coast, the life cycle is shorter (Persson, 1981).

Central to the model is the interaction between rainfall and armyworm biology. The model makes the assumption that armyworm population dynamics are ultimately determined by patterns of rainfall in time and space. Five categories of mutually exclusive rainfall pattern are defined (Table 2). These were chosen as the minimum necessary to describe the major effects on armyworm populations.

As the basic units of the model are the week and the degree square, it is necessary to summarize the prevailing rainfall pattern for the week over the degree square. 'Dry' means less than 0.1 mm in a week. 'Light rain' refers to rainfall not exceeding 10 mm in any day and, therefore, not likely to be associated with strong storm structures. 'Isolated rainstorms' implies the presence of substantial storms with convergent wind-flows but few in number and patchy in spatial distribution. 'Occasional widespread rainstorms' refers again to substantial storms, again interspersed with fine weather but more complete in their spatial coverage. 'Frequent widespread storms' implies more general heavy rain, widespread in time and space such that strong convergent wind-flows are either absent or too complex to initiate strong moth concentration.

Table 2 Variables and their alternative states used in the armyworm model

Variable	State	Symbol	Scale point	Numeric Approximation
Weather *W*	dry	d		No rain
	light rain	lr		No rainstorms
	isolated rainstorms	ir		1–2 rainstorms per week
	occasional widespread rainstorms	ow		3–4 rainstorms per week
	frequent widespread rainstorms	fw		5–7 rainstorms per week
Fecundity *F*	very low	vl	1	5 eggs/female = $2e^1$
	medium	m	4	110 = $2e^4$
	high	h	5	297 =$2e^5$
	very high	vh	6	807 = $2e^6$
Food quality *Q*	very low	vl		
	low	l		
	medium	m		
	high	h		
	very high	vh		
Larval mortality *M1* and *M2*	very high	vh	4	98% = $100(1-e^{-4})$
	high	h	3	95% = $100(1-e^{-3})$
	medium	m	2	86% = $100(1-e^{-2})$
	low	l	1	63% = $100(1-e^{-1})$
	negligible	n	0	0 = $100(1-e^{-0})$
Aggregation of airborne moths *A*	low	l		
	medium	m		
	high	h		
Emigration rate *E*	extremely high	eh	5	99.3% = $100(1-e^{-5})$
	very high	vh	4	98% = $100(1-e^{-4})$
	high	h	3	95% = $100(1-e^{-3})$
	medium	m	2	86% = $100(1-e^{-2})$
	low	l	1	63% = $100(1-e^{-1})$
	negligible	n	0	0 = $100(1-e^{-0})$

Direct effects of rainfall

Fecundity (F). Female *S. exempta* can lay up to 1000 eggs in the space of a few days and the major limiting factor is the availability of water, though only a small amount is required (Page, 1988). Four fecundity categories are defined in the model (Table 2). If the weather in week *t* (in a particular degree square) is dry (*d*), then armyworm fecundity in that degree square is very low. Light rain (*lr*) is sufficient to boost fecundity to medium. The complete relationship between rainfall and fecundity can be summarized symbolically as:

$$W\{d,lr,ir,ow,fw\}_t \Rightarrow F\{vl,m,h,vh,vh\}_t \qquad \text{eqn. 1}$$

where W = weather, which in any week, t, can be in state d, lr, etc., and F = fecundity, the value of which for week t (vl, m, etc.) is determined by W (all symbols defined in Table 2).

Mortality (M1). Very young larvae are susceptible to drowning (Rose *et al.*, 1995) which is only likely to occur when heavy rain is widespread. Heavy rain and overcast conditions also increase mortality because of the effects of pathogens (Persson, 1981). Five mortality categories are defined, ranging from negligible to very high (Table 2). The correspondence to rainfall is:

$$W\{d,lr,ir,ow,fw\}_t \Rightarrow M1\{l,l,l,h,vh\}_t \qquad \text{eqn. 2}$$

Aggregation of airborne moths (A). Armyworm outbreaks usually occur when sufficient individuals have become aggregated and breed synchronously. This is thought to occur when mesoscale convergent wind-flows concentrate airborne moths (Pedgley *et al.*, 1982). In the model, there are three levels of population aggregation, determined by the weather prevailing at the adult stage. The degree of aggregation for the weekly cohort within each degree square persists until pupal emergence, when the degree of aggregation of the new generation is again determined by the prevailing weather. The strongest concentrating effects are assumed to be associated with discrete but substantial storms, so:

$$W\{d,lr,ir,ow,fw\}_t \Rightarrow A\{l,l,m,h,l\}_t \qquad \text{eqn. 3}$$

Food quality (Q). This is described on a five point scale from very low to very high (Table 2). In non-crop areas, armyworm feeds on grasses and, until the first rains of the season, little green foliage is present. With the first storms a flush of young grass, high in minerals and nutrients, grows rapidly so that within a week there is very high quality food available for any young armyworm present. The flush of vegetation at the start of the rainy season is assumed not to take place until one of the three categories of storm occurs. Until the week of the first storms, food quality is assumed to be very low. In the week after the first storms, food quality rises to very high if storms are widespread (*ow* or *fw*) but only to high if the storms are isolated (*ir*), as in the latter case it can be assumed that many parts of the area will receive insufficient rain to initiate the flush of vegetation. Thereafter, the food quality is assumed to decline gradually, falling by one category every 3 weeks until *vl* is reached. Once widespread storms (*ow* or *fw*) have taken place, storms in subsequent weeks have no impact on food quality. However, if widespread storms have *not* taken place, further isolated rainstorms (*ir*) mean that food quality is reset to high, on the assumption that further flushes of grass will be initiated in new locations. These effects can be summarized as:

$$W\{d,lr\}_t \Rightarrow Q\{vl,vl\}_{t+1} \text{ where } W\{ir,ow,fw\} \text{ has not already occurred,}$$
$$W\{ir,ow,fw\}_t \Rightarrow Q\{h,vh,vh\}_{t+1} \text{ where } W\{ow,fw\} \text{ has not already occurred,}$$
$$\text{otherwise, } Q_{t+1} = Q_t \text{ where } (t \bmod 3) \neq 0 \text{ or } Q_t = vl,$$
$$Q_{t+1} = Q_t\text{-}1 \text{ where } (t \bmod 3) = 0 \qquad \text{eqn. 4}$$

Indirect effects of rainfall

Emigration (E). The extent of emigration of adult armyworm from the site of emergence is thought to be determined by two main effects. Firstly, if the moths have developed from a population of gregarious larvae, they are more likely to be long fliers (Parker and Gatehouse, 1985). Thus high levels of aggregation of larvae are assumed to lead to a greater propensity for subsequent emigration. This is an indirect effect of earlier rainfall. Secondly, when rain is present, moths are less likely to emigrate long distances, as they can obtain the moisture required for maturation locally and also the wind-flow in the vicinity of storms is likely to prevent long-distance migration. As noted above, the degree square is the unit of space, and the level of emigration from the degree square is obviously lower than that from the individual outbreak site. The current weather and the level of aggregation of the previous generation (determined 5 weeks earlier) together determine the rate of emigration. For example, if the weather is dry ($W = d$) the emigration rate will be medium if larval aggregation was low ($A = l$) but extremely high if $A = h$. All combinations are specified below:

$$W\begin{Bmatrix} d \\ lr \\ ir \\ ow \\ fw \end{Bmatrix}_t \& A\{l\}_{t-5} \Rightarrow E\begin{Bmatrix} m \\ l \\ l \\ n \\ n \end{Bmatrix}_t, \qquad W\begin{Bmatrix} d \\ lr \\ ir \\ ow \\ fw \end{Bmatrix}_t \& A\{m\}_{t-5} \Rightarrow E\begin{Bmatrix} vh \\ h \\ h \\ l \\ l \end{Bmatrix}_t,$$

$$W\begin{Bmatrix} d \\ lr \\ ir \\ ow \\ fw \end{Bmatrix}_t \& A\{h\}_{t-5} \Rightarrow E\begin{Bmatrix} eh \\ vh \\ vh \\ h \\ h \end{Bmatrix}_t \qquad \text{eqn. 5}$$

Mortality (M2). Early instar larvae are thought to suffer high mortality if food quality is low. In the model, the correspondence between mortality of young larvae and food quality is:

$$Q\{vl,l,m,h,vh\}_t \Rightarrow M2\{vh,h,m,l,n\}_t \qquad \text{eqn. 6}$$

Specifying the dynamics of the armyworm population

Having defined the functional relationships, it is possible to specify the dynamics of the armyworm population from one week (t) to the next (t+1) in each degree square. The sequence of events in the model is shown in Table 3. Population size is described on a relative scale because it is frequently possible to say that the population would be expected to become smaller or larger but not by how much. To ensure mathematical consistency, however, it is useful to relate qualitative judgements to a quantitative scale. Population growth is an inherently exponential process so steps on a logarithmic rather than a linear scale were employed throughout to specify population change. The population model can be formulated very simply by virtue of the fact that the number in each life stage and the rates of fecundity, mortality and emigration are steps on a logarithmic scale. Thus, the fecundity rate category indicates the number of points the population moves up the logarithmic population scale and the mortality and emigration rate categories, the number of points the population moves down the scale (Table 2).

Where populations combine, as occurs when immigrants to a degree square combine with a population already present in a degree square, the combined population is rounded to the nearest point on the logarithmic scale. The combined population is approximately equal to the larger of its two components ($e^{n+1} = e^{n} + e^{n+1}$). If the local and immigrant populations are the same, then the population is augmented one scale point ($e^{n+1} = e^{n} + e^{n}$). This leads to a set of three alternative expressions for the adult stage, according to the relative size of the immigrant and existing local populations. Note also that, by convention, the population variables refer to the number present at the *end* of each stage.

The dynamics within each degree square are specified by:

$$A_{t+1} = P_t - E_{t+1} + F_{t+1} \qquad \text{where } I_{t+1} < P_t - E_{t+1},$$
$$A_{t+1} = I_{t+1} + F_{t+1} \qquad \text{where } I_{t+1} > P_t - E_{t+1},$$
$$A_{t+1} = P_t - E_{t+1} + 1 + F_{t+1} \qquad \text{where } I_{t+1} = P_t - E_{t+1}$$

$$LS_{t+1} = A_t - M1_{t+1} - M2_{t+1}$$
$$LL_{t+1} = LS_t$$
$$PP_{t+1} = LL_t$$
$$P_{t+1} = PP_t \qquad \text{eqn. 7}$$

Table 3 Algorithm sequence used in the armyworm model

End of life stage	End of week	Action sequence	Action is function of
Pupae	t -1	Remove emigrants	Degree of aggregation of last generation (determined in week t -5) and weather during week t,
		Add immigrants	Driving variable
		Determine level of aggregation of the new generation	Weather during week t
		Action fecundity	Weather during week t
Adults/eggs	t	Impose mortality on young larvae due food quality	Food quality during week t +1, itself a function of weather history)
		Impose mortality on young larvae due to drowning and disease	Weather during week t +1
Young larvae	t +1		
Older larvae	t +2		
Prepupae	t +3		
Next generation of pupae	t +4		

The number of emigrants generated by a degree square are rounded to the nearest scale point, in a similar way to the calculation of immigrants. Thus, the number of emigrants from a degree square in the following week (G_{t+1}) are determined by the number of pupae this week (P_t), and depend upon the emigration rate the following week:

$$
\begin{aligned}
G_{t+1} &= P_t && \text{where } E_{t+1} > 1, \\
G_{t+1} &= P_t - 1 && \text{where } E_{t+1} = 1, \\
G_{t+1} &= 0 && \text{where } E_{t+1} = 0 \qquad \text{eqn. 8}
\end{aligned}
$$

Specifying the dispersal of emigrants

To provide a spatial model of armyworm population processes, the model for a single degree square was replicated over a grid of squares linked by migration of moths between squares. As discussed above, the numbers of moths emerging at an outbreak site which migrate away from the site depend both on the aggregation of the emerging moth population and on the weather conditions at the time of their potential dispersal. The direction and distance of migration of armyworm moths between breeding sites depends primarily on the speed and direction of the wind during the migration period. To model migration, the mean direction a and distance r of travel are estimated and this allows the degree squares which are most likely to be destinations of the migrating moths to be calculated (see below). Whether moths arriving at a new destination concentrate to form a new outbreak or remain as a low density scattered population depends on the weather conditions at the destination.

To distribute migrating moths emerging from a degree square, the co-ordinates of the mean destination, $\bar{x} = r \cos \alpha$ and $\bar{y} = r \sin \alpha$, were calculated. The distance from the mean destination to the centre of each degree square

$$s = \sqrt{(\bar{x} - x)^2 + (\bar{y} - y)^2} \qquad \text{eqn. 9}$$

was then calculated, and discrete realizations of the normal distribution with standard deviation σ, were then used to determine the relative fraction of emigrants going to each square, depending on the proximity of the square to the mean destination.

$$R_{x,y} = \exp \left(\frac{s}{2\sigma^2}\right) \Big/ \sigma \sqrt{2\pi} \qquad \text{eqn. 10}$$

Normalizing the discrete values across all squares gives the proportion of immigrants going to each destination square.

$$\omega_{x,y} = R_{x,y} \Big/ \sum_{x=min,\, y=min}^{x=max,\, y=max} R_{x,y} \qquad \text{eqn. 11}$$

The number (in logarithms) of emigrants from the source square going to square x,y as immigrants I, is $\ln(\omega_{x,y} \exp(E_t))$ and these were combined with the local population of moths in square x,y according to eqn. 7.

The distance and direction of migration can be estimated in a variety of ways. Real-time synoptic wind-flow information could be used if available on a regular basis. In the absence of real-time information, the prevailing wind, specific for each month and each degree square, was used to estimate the probable displacement of moths for a particular time and place. The prevailing wind-flow patterns in Tanzania are reasonably stable and usually veer from north-east to south-east over the course of the armyworm season (Tucker *et al.*, 1982). Moths emerging from a degree square are likely to be distributed over several squares depending on the variability in the windfield during the week of moth emergence. The extent of this dispersal is represented by the standard deviation around the mean destination. An appropriate value of σ can be estimated by testing model predictions against existing data.

Remotely sensed data

For real-time forecasting, rain-gauge data are generally only available for synoptic meteorological stations, of which there are, for example, 28 covering the whole of Tanzania. Meteosat data are, however, available on a daily basis for a resolution of about 7 km over eastern Africa. The conversion of Meteosat daily CCD images to degree square data usable in the rule-based model and also suitable for sending in text format by e-mail to armyworm forecasters in Tanzania is carried out as follows:

- collect half-hourly Meteosat infra-red images using a Primary Data User Station and program the system to calculate daily CCD images for temperature thresholds of -30, -40, -50 °C
- archive daily CCDs to tape
- convert daily Meteosat CCD images to IDA GIS format
- process images for a degree square grid covering Tanzania taking the maximum pixel (data unit) value of the CCD for each day for a week (mean values could also be taken).

Figure 1a shows an example of a weekly sequence for a period of mostly isolated storms in November 1997 for an area 33° to 39° E and 2° to 10° S, which encompasses the armyworm outbreak risk area in Tanzania and southern Kenya. The e-mail is read into a spreadsheet to produce the maps shown in Figure 1a and these CCD summaries are in current use to aid the production of the weekly armyworm forecast produced by Pest Control Services. The summaries are compared with armyworm trap catch reports for that week to assess outbreak risk. The daily CCD data can also be used to establish the rainfall categories for the week as a basis to drive the model (Figure 1b) with Table 4 indicating a tentative classification of rainfall categories.

Comparison of model predictions with outbreak data

The probability of armyworm outbreak occurrence following particular rainfall categories was tested using historical data. Data were available on the occurrence of outbreaks in particular districts together with rain-gauge readings from the same degree square in which the outbreaks took place. The localized nature of rainstorms and the scattered distribution of rain gauges meant that the rainfall records did not necessarily reflect the meteorological conditions at the armyworm outbreak site. Given this caveat it was none the less useful to examine the conditional probability of armyworm outbreaks given the rainfall conditions recorded at a point within the same degree square. Rainfall was categorized on a weekly basis using the same classification scheme devised for the model (Table 5). The week of occurrence of armyworm outbreaks was also recorded. A total of 145 datasets spanning the period of the armyworm season in Tanzania, November to March inclusive, were examined. These were distributed over 11 years (1975, 76, 80, 81, 83, 86, 88, and 92–95) and 25 locations throughout Tanzania.

In this set of data, 164 outbreaks were recorded. These records refer to the presence of middle or late-instar larvae, and allowing an appropriate interval for egg and larval development, it was assumed that an outbreak in week *t* was due to the arrival (or emergence) of adult moths in week *t*-2. Rainfall in the week of moth arrival (*t*-2) and in the following week during development of early-instar larvae (*t*-1) are important in armyworm population processes as discussed earlier. To test for an association between the occurrence of particular rainfall patterns and probability of outbreaks, the frequency of the 2-week sequence which preceded outbreaks was compared with the frequency of occurrence of such sequences in the dataset as a whole. Rainfall was categorized as being one of five mutually exclusive categories but category 5 (frequent widespread storms) only occurred on two occasions, so these cases were amalgamated with category 4 (widespread storms). Using four categories, there are sixteen possible 2-week sequences: 1,1; 1,2; .... 4,4.

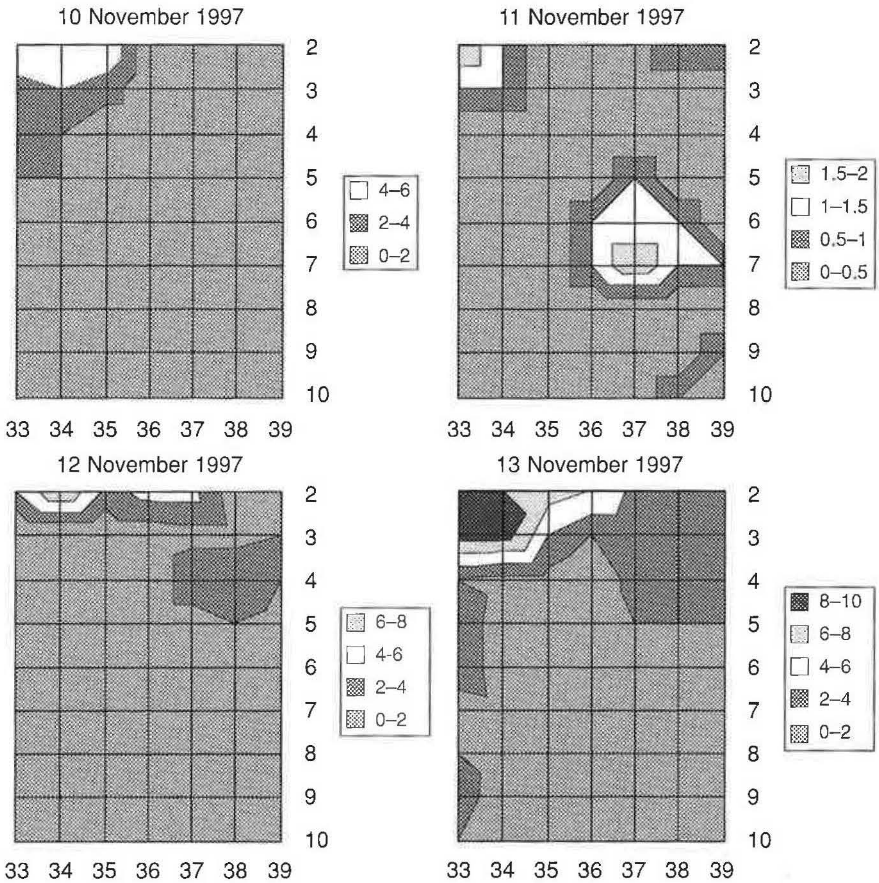
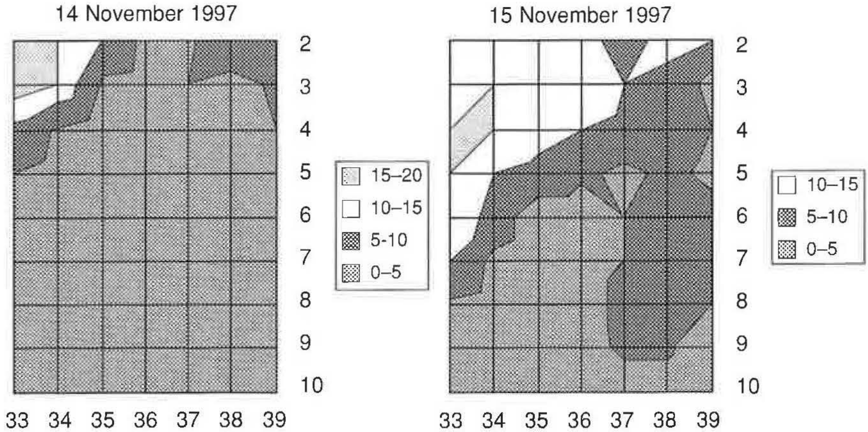
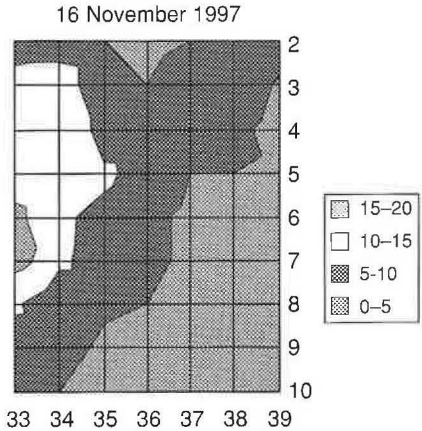


Figure 1a Examples of weekly sequence summary maps of maximum CCD (hours) for each degree square for the area 33° to 39° E and 2° to 10° S.





Max cold-cloud duration in each degree square (squares labelled by the NW corner, i.e. grid point 5,35 is the value for square 5–6 S, 35–36 E)

Figure 1a *cont.*

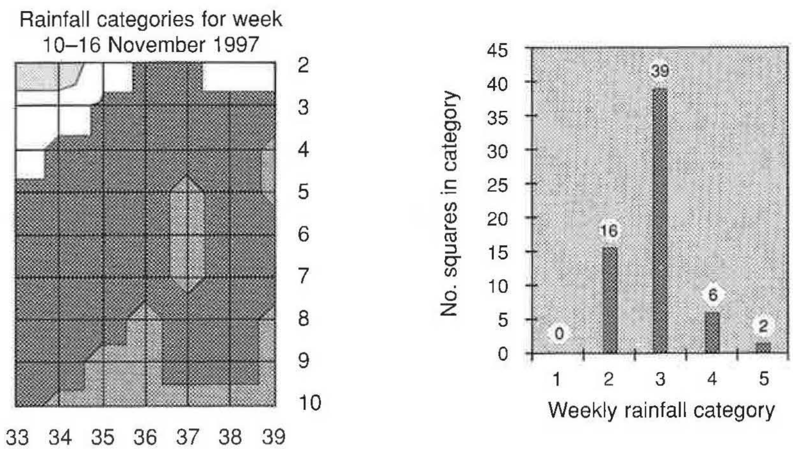


Figure 1b A map and frequency distribution of the rainfall categories for the week derived from the daily maximum CCD data according to Table 4.

Table 4 Categorization of rainfall in a degree square from weekly CCD summaries

CCD during the week	Number of days with > 4 hours CCD	Rainfall category for the week
0	0	1. Dry
> 0	0	2. Light rain
> 0	1–2	3. Isolated storms
> 0	3–4	4. Occasional widespread storms
> 0	5–7	5. Frequent widespread rain

Table 5 Categorization of rainfall in a degree square from weekly rainfall summaries

Total rain during the week	Number of days in which more than 10 mm rain falls	Rainfall category for the week
0	0	1. Dry
>0	0	2. Light rain
>0	1–2	3. Isolated storms
>0	3–4	4. Occasional widespread storms
>0	5–7	5. Frequent widespread rain

The frequency of each of these sequences prior to armyworm outbreaks was compared with an expected distribution calculated from the frequency of these sequences in the dataset as whole. It was necessary to combine several of the categories shown in Figure 2 (sequence 1,3 with 1,4; 2,3 with 2,4; 3,3 with 3,4; and 4,1 to 4,4 inclusive) in order to give appropriate sample sizes for comparison, and having done so, the observed and expected differed, $\chi^2 = 17.02$, 9 d.f., $P<0.05$. It can thus be concluded that certain rainfall sequences were more or less associated with armyworm outbreaks than would be expected by chance.

Expressing the results as conditional probabilities allows some comparisons to be made with model predictions. As a baseline for comparison the probability of an outbreak irrespective of any rainfall or location information (the prior probability of an outbreak in any week in any district) was 0.06, i.e. in the absence of any information, there was a 6% chance of an outbreak. Of interest here was how this baseline probability was changed when the rainfall pattern was known. The conditional probability was greatest (0.24) when widespread rains were followed by dry weather (sequence 4,1; Figure 2). The probability was higher than the baseline when isolated storms in the week of moth arrival were followed by any weather category (3, followed by any category) and when widespread storms were followed by dry weather or light rain (4, followed by 1 or 2). Other weather patterns gave conditional outbreak probabilities similar or less than the baseline of 0.06.

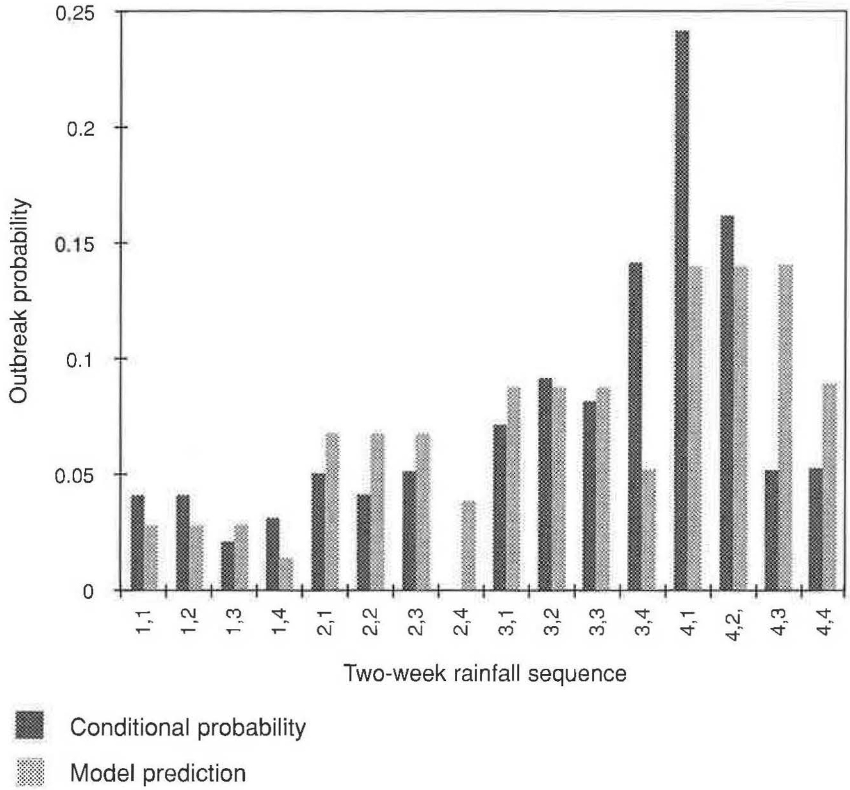


Figure 2 Historical records of rain-gauge data and outbreaks compared with model predictions for a dataset of outbreak events over 11 years and 25 locations in Tanzania. Rainfall category codes: dry (1), light rain (2), isolated storms (3), occasional widespread storms (4).

The conditional probabilities derived from historical records refer to outbreak *incidence*, i.e. whether or not outbreaks occurred in the degree square given a certain weather pattern. The model predicts outbreak *severity* within the degree square, i.e. the magnitude of the armyworm population expected in the degree square and the extent to which it is likely to be concentrated to form outbreaks. Making allowance for the difference in meaning, the historical evidence and the predictions of the model are in good agreement.

The magnitude of the simulated armyworm larva population predicted by the model in a particular week depends on earlier events but for purposes of comparison in Figure 2, it was assumed that 6 weeks of isolated storms with no new armyworm arrivals were followed by the specified rainfall sequence accompanied by an armyworm influx. This gives the outbreak risk shown in Figure 2. This is the product of log population size and aggregation level. Thus, the larger and more aggregated the population of late-instar larvae the greater the outbreak risk.

As can be seen in Figure 2, the assumptions of the model were such that the lowest outbreak risk rating occurred when dry conditions in the week of moth arrival (*t*-2) were followed by widespread rain during development of the small larvae (*t*-1). Dry conditions at *t*-2 results in a low level of aggregation (eqn. 3) and low fecundity (eqn. 1) of immigrant moths and low grass quality for young larvae at *t*-1 (although this also depends on prior rain, as indicated in eqn. 6). Wet conditions in *t*-1 mean high mortality of early-instar larvae (eqn. 2). At the other end of the scale, highest outbreak risk rating occurred when widespread storms were followed by dryer conditions (4 at *t*-2, followed by 1, 2, or 3 at *t*-1). The data and model appear to be in agreement with '4,1' having the highest outbreak probability and '1,4' the second lowest in the dataset examined (Figure 2).

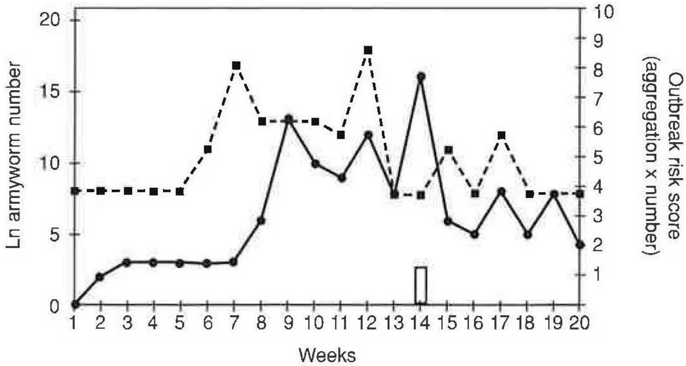
Two particular discrepancies were noted. First, in the model, isolated storms (at *t*-2) followed by widespread storms (at *t*-1) gave a lower risk rating than isolated storms followed by drier weather. The trend in the historical records was the reverse. The underlying assumption of the model was that moths concentrated at potential outbreak sites by isolated storms in week *t*-2 would be likely to suffer some mortality if hit by any of the widespread storms occurring in week *t*-1. Second, in the model, it was assumed that widespread storms followed by isolated storms resulted in just as high a risk rating as did widespread storms followed by drier weather. This was not the case with the historical data where the outbreak probability associated with '4,3' was about one third that associated with '4,2'. The rationale of the model is that following the concentration of the armyworm population by widespread storms in week *t*-2, a relatively small proportion would be likely to be hit by isolated storms in week *t*-1. The mortality of early-instar larvae associated with dry weather, light rain and isolated storms was, therefore, assumed to be the same (eqn. 2). These discrepancies suggest that it is important to examine the impact on model predictions of modifications to the relationship between rainfall and larval mortality.

Analysis of this set of historical records provided a useful comparison with model predictions. The model was based on relationships and interactions which were known to occur but in many cases the magnitude of the effects was uncertain. The model effectively represented the qualitative understanding of armyworm population processes with a rule-based structure and could thus provide a relative rather than absolute measure of outbreak risk.

Using the model

In each degree square, armyworm population dynamics are simulated. Examples of model output for a single location (Figure 3) indicate the wide range of outbreak outcomes that occur depending on the pattern of moth arrival and its interaction with rainfall events. The model is currently set up to predict outbreak risk in the next armyworm generation across a grid of 20 degree squares following an outbreak in a potential source square. The parameter input screen of the model (Figure 4) allows the distance, direction and dispersion of moths leaving the source square to be specified. The expected frequency of each weather category is also

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Rain	1	1	1	1	1	2	3	4	4	5	3	4	1	1	1	1	1	1	1	1
Moths							1													



Example 1

Wk 7 Moths arrive and are reconcentrated where they encounter the isolated storms

Wk 8 Small larvae suffer because and grass food quality is still patchy

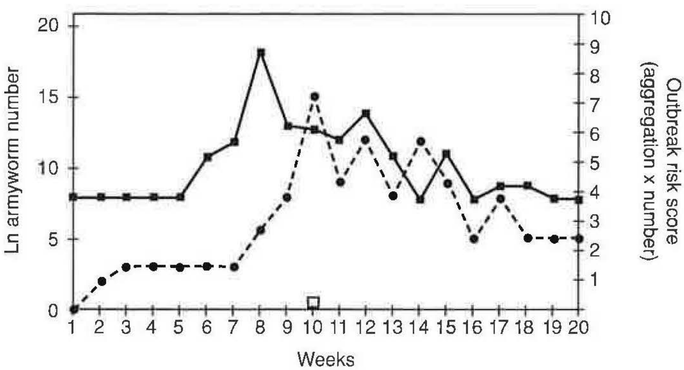
Wk 9 Large larva numbers relatively low – low outbreak risk

Wk 12 Next generation of moths emerge, under conditions of local strongly convergent wind-flows and most are retained in degree square and reconcentrated

Wk 13 Good conditions for developing small larvae

Wk 14 High outbreak risk with large population of aggregated large larvae

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Rain	1	1	1	1	1	2	3	4	4	5	3	4	1	1	1	1	1	1	1	1
Moths								1												



Example 2

Wk 8 Moths arrive and are strongly reconcentrated by convergent wind-flows

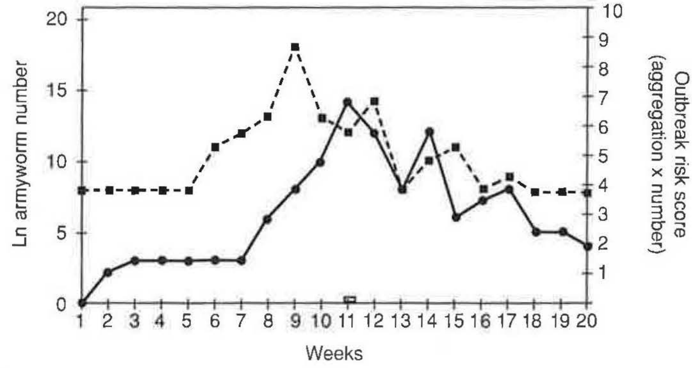
Wk 9 Grass quality has reached its peak throughout the square as widespread storms have occurred and food for small larvae is very good, but losses also occur due to continuing wet conditions

Wk 10 Large larva numbers moderate and the population is aggregated, leading to moderate outbreak risk

Wk 13 Next generation of moths emerge, under dry conditions and are highly aggregated. Most leave the degree square.

Figure 3 Output produced by the model for a single location. For the same sequence of rainfall categories, examples show the impact of different patterns of moth arrival on moth abundance (– – – –), large larva abundance (——) and the index of outbreak risk, abundance x aggregation (bar).

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Rain	1	1	1	1	1	2	3	4	4	5	3	4	1	1	1	1	1	1	1	1
Moths									1											



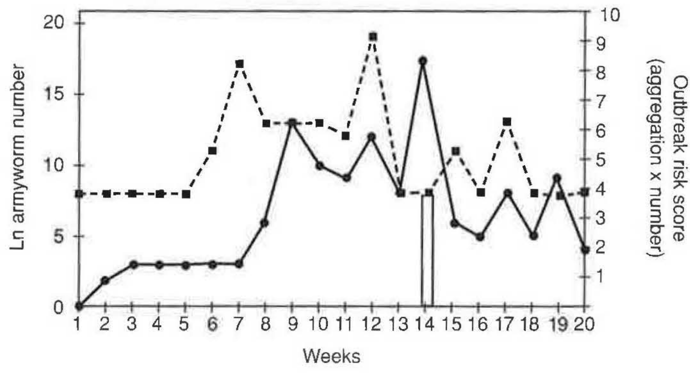
Example 3

Wk 9 Moths arrive and are strongly reconcentrated by convergent wind-flows

Wk10 Very wet conditions cause mortality to young larvae

Wk 11 Large larva numbers moderately low; small outbreak risk

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Rain	1	1	1	1	1	2	3	4	4	5	3	4	1	1	1	1	1	1	1	1
Moths							1					1								



Example 4

Wk 7 Moths arrive as in Example 1

Wks 8 & 9 Same scenario as Example 1

Wk12 Next generation of moths emerge, under conditions of local strongly convergent wind-flows and most are retained in degree square and reconcentrated. Further moths arrive from another degree square and are also reconcentrated

Wk13 Good conditions for developing small larvae

Wk 14 Very high outbreak risk due to multiple moth arrivals to square at an interval of one generation

Figure 3 ***cont.***

Armyworm rule-based model. Version 1.3 March 1998
Predicts outbreak risk over a 20 degree square grid extending 2 degrees N and S, and 3 W from square with moth source

Parameters determining **migration**
(alter values in red boxes as required

Distance	1.5	Average measured in square widths
Direction	300	Average angle (West = 270)
Dispersion	0.5	Standard deviation of dispersion

Resulting percentage to each destination square
(degrees W and N relative to source)

W/N	3	2	1	0	
2	0	1	2	0	
1	0	21	47	2	
0	0	8	17	1	<- Source square
-1	0	0	0	0	
-2	0	0	0	0	

Parameters determining **weather category** probability (alter values in red boxes)

Category	Type	Prob
dry	1	0
light rain	2	0.25
isolated storms	3	0.62
widespread storms	4	0.1
frequent widespread storms	5	0.03

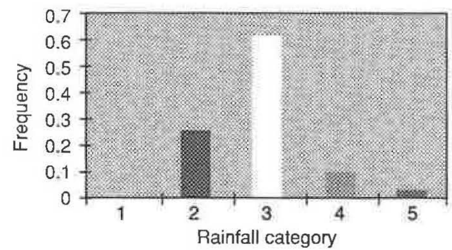


Figure 4 Parameter input screen allowing the user to specify armyworm dispersal parameters and rainfall category frequencies.

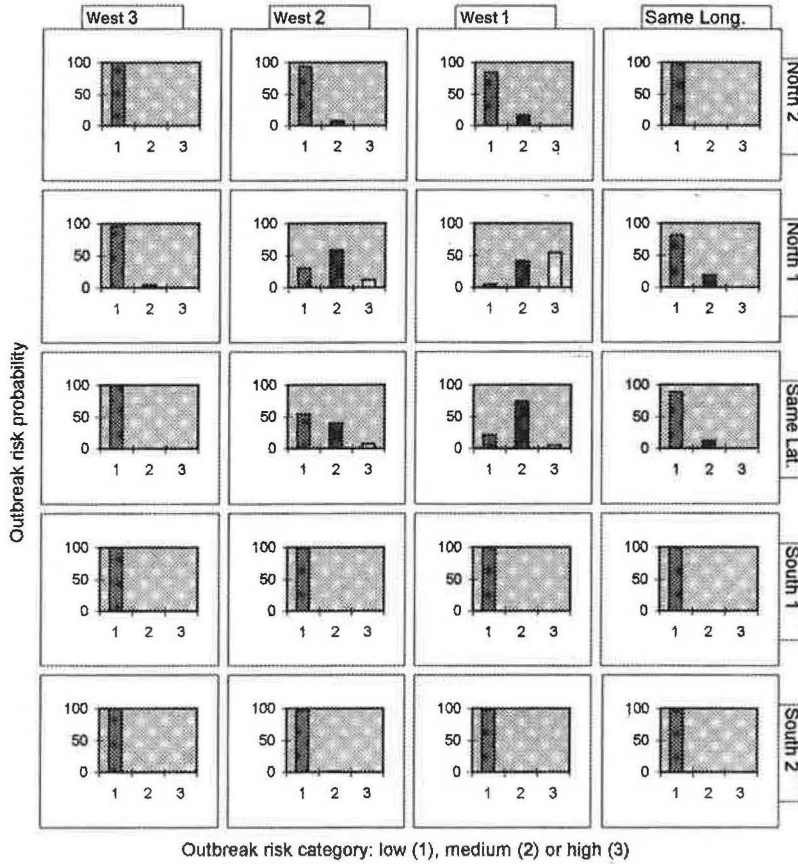


Figure 5 The probability of low, medium and high armyworm outbreak risk in each degree square based on a 100 run ensemble forecast, for example, in square W1, N1, the probability of high outbreak risk is about 50%, medium 45%, and low 5%, and for this square the forecast 'outbreak risk medium to high' might be given as a result.

entered: in the example shown in Figure 5, the values were taken from Figure 1b. Moths from the source are distributed across the possible destination squares and occurrence of subsequent outbreaks depends upon the weather patterns encountered in each square.

When projecting forward to the next armyworm generation, it may only be possible to use the same expected weather pattern for all squares since the actual rainfall will not be known. The potential impact of different scenarios, for example, 'dryer than usual', 'wetter than usual', and average, can be examined by category frequency distribution. For short-term forecasts (1 week ahead), the significant rainfall (or rainstorm distribution from satellite data) is likely to have already occurred and may be known from rain-gauge or satellite information. Square-specific rainfall category data can then be used.

Here we consider the case where only a general weather forecast of rainstorm probability for a large area of Tanzania is known. Therefore, we take the same rainfall frequency distribution for all squares and use an ensemble forecasting technique (Zhang and Krishnamurti, 1997), to estimate outbreak risk. Forecasters at Pest Control Services describe armyworm risk as low, medium or high and the index of outbreak risk (abundance x aggregation) was categorized accordingly. Repeated runs of the model (usually 100) were made for different realizations of the rainfall category distribution and the number of occurrences of low, medium and high outbreak risk in each square was recorded to estimate the probability of these events (Figure 5). Model output such as that in Figure 5 can be used to help judge not only the most likely outbreak risk level in a square but also assess the variability associated with this estimate. A major benefit provided is to allow some sensitivity analysis of outbreak prediction to changes in expected armyworm dispersal and future rainfall scenarios.

CONCLUSION

The tools described in this chapter illustrate how forecasts can be improved by enabling large amounts of information from a variety of sources to be summarized, processed and analysed in a short time. The success of the resulting forecasts depends critically on the accuracy and timely availability of the raw data, the validity of the models and the efficiency of the dissemination of relevant information to decision-makers and farmers.

Both satellite data and synoptic meteorological data are potentially available on a regular, reliable, schedule, although failures do occur occasionally. The operation schedule for African armyworm light and pheromone traps involves daily counting of catches and weekly radio transmission of the information to the forecasting office. Initial reports of occurrence of African armyworm outbreaks or desert locust populations are largely dependent on farmers or pastoralists reporting sightings to agricultural extension officers. They are, therefore, sporadic and incomplete. It is only when extension officers or other trained staff become involved that reports begin to be more complete. Even then, in developing countries, lack of infrastructure, reliable communication and financial resources often make the regular acquisition and processing of such data difficult.

Models of the development of desert locust and African armyworm populations are both based on many years research but information gaps exist and as much information is qualitative, rule-based models provide a way to utilize this information to build models. Trajectory analyses of adult migration are used for both desert locusts and African armyworm but only give case studies of historical movements. Use of trajectory analysis for real-time forecasting requires large amounts of detailed data for wind-flows that is usually impractical to obtain. The rule-based model as described here is relatively crude in its spatio-temporal resolution but this may be appropriate as the current forecast is issued at the same resolution provided by the model. It also has a major advantage in that it is possible to set up sustainable procedures to provide the data to run the model. As such, the model has considerable potential to aid the forecasting process and if it is found to give reliable forecasts may be able to replace some of the experience lost when experienced forecasters retire or move to other work. Existing knowledge is incorporated in a form that can be used by new computer-literate but inexperienced forecasters in eastern Africa.

The next stage is to run the armyworm model alongside the existing forecasting procedure to establish its performance. An iterative process of testing and improvement is envisaged in collaboration with the end-users. It should be emphasized that the model described here is a prototype which is likely to be modified before it becomes operational. Identification of the decision-makers and their requirements has been an essential feature of model development (Mumford and Norton, 1993; Day and Knight, 1995) and presentation of forecast outputs in forms appropriate for planners of control campaigns, local agricultural extension officers is a central objective. A forecast is of no value unless actions change as a result of the information provided by the forecast (Day and Knight, 1995) and the final test remains whether pesticide targeting is improved and environmental side-effects reduced.

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Chapter 5

DECISION-MAKING TOOLS FOR MORE COST-EFFECTIVE PEST MANAGEMENT IN MILLED RICE BAG-STORES

Rick J. Hodges

INTRODUCTION

The development of formal decision-making tools for the management of large-scale grain storage offers opportunities for efficiency gains. In recent years, several 'expert systems' which can simulate a number of aspects of grain storage and pest management have been developed for this purpose and include Stored Grain Advisor in the USA (Flinn and Hagstrum, 1990), Grain Pest Advisor in the UK (Wilkin *et al.*, 1990) and Pestman in Australia (Longstaff, 1994). Although originally developed with the intention of providing direct management advice to operational staff, these systems have so far not gone beyond offering training facilities whereby managers can see the consequences of their actions and learn optimal strategies in the face of complex situations.

Little headway has been made in preparing or using wide-ranging decision tools for grain store management in developing countries, although Pestman has been adapted for use in China and is currently being adapted for use in milled rice stores in Indonesia (Longstaff, 1998). On the other hand, two decision-support tools dealing with specific aspects of grain storage have been prepared especially for use in developing countries. Cereanly has been devised to help store managers in the francophone countries of the Sahel in West Africa decide the fate of national food security stocks based on grain quality criteria (German Technical Aid Agency, GTZ) and for the Indonesian National Logistics Agency (BULOG), an insect pest monitoring method and a Fumigation Decision Support System (FDSS), have been developed, with the help of the UK's Department for International Development (DFID), to improve the cost-efficiency of pest management in milled rice stores (Hodges *et al.*, 1985; Haines *et al.*, 1991; Hodges *et al.*, 1996b). This chapter describes decision-making processes, in relation to insecticide spraying and fumigation, that have been possible as a result of adopting a more sensitive and reliable means of estimating insect populations in milled rice stores.

CONVENTIONAL PEST MANAGEMENT OPTIONS IN TROPICAL MILLED RICE STORES

Marketing boards and traders in developing countries maintain milled rice in jute or polypropylene bags in large stores. This is done to supply grain markets and maintain food security, especially in urban areas. The grain may remain in store for extended periods, frequently in excess of a year and during this time the stocks are subject to attack by insects. Under warm, humid conditions the damage can be especially severe, and if left unchecked, may result in the stock being downgraded to animal food or, in some cases, being completely unmarketable. To prevent such losses, insects are killed by fumigation and by spraying store surfaces with residual insecticide (Figure 1). Admixture of insecticide directly to the grain, a method used for many other cereals, is not considered appropriate for milled rice because normally it does not undergo further industrial processing before human consumption.

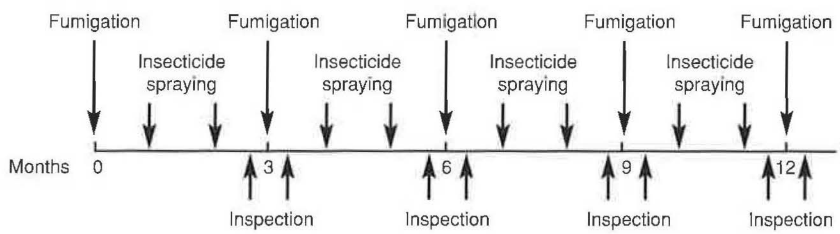

Figure 1 A typical pest management annual schedule employed to limit losses caused byinsects in milled rice bag-stores.

Fumigation is undertaken by confining grain stocks with a toxic gas; this is usually done by placing the grain beneath gas-tight sheets. Provided the insects are exposed to sufficient gas for a sufficient time then all life stages will be killed. The precise conditions required for a fully effective fumigation are usually laid down in national codes of practice. However, such treatment does not prevent the stock being reinvaded by insects once sheets have been removed and the fumigant gas has dispersed. Consequently, if stocks have not been marketed within a month or two after fumigation then a further treatment may be necessary. In many countries, once fumigation is complete, the stores are sprayed with residual contact insecticide. This procedure is then repeated every 3 to 6 weeks in order to kill invading insects and thus reduce the need for refumigation. These insecticide spray treatments are individually cheaper than a fumigation, hence the strategy is employed in an attempt to reduce costs.

The conventional means of controlling pest management in milled rice stores is to operate a calendar system of treatment with fumigations being repeated every 3 months (Figure 1). There is little or no regard for the actual size of the insect population infesting the stock. A pre-fumigation inspection may be used to delay treatment if it appears that few or no insects are present and a post-fumigation inspection may be undertaken soon after treatment to confirm its efficacy. The post-fumigation inspection relies on the detection of adult insects. As the most resistant stages to fumigant gases are eggs and pupae, which are difficult to detect, such inspections are usually unreliable.

INCENTIVES FOR IMPROVED PEST MANAGEMENT

Fumigation treatments are expensive, costs vary greatly between countries, but a typical example would be about US$ 2100 for a warehouse containing 3000 tonnes of grain (1990 prices). Compared with the value of the grain stock, treatment costs are small. However, in absolute terms, for systems that are frequently under severe financial constraint, such costs represent a substantial investment. Therefore, there are financial advantages in ensuring that fumigations are:

(a) not undertaken unnecessarily;

(b) not undertaken late, since a significant quality decline will already have occurred; and that

(c) they are done to a sufficiently high standard that a full insect kill is achieved, otherwise a costly refumigation will be required.

Points (a) and (b) also apply to routine insecticide spraying. However, there is a further point to consider. The spray treatments are used because they save money by reducing the necessity for more costly fumigation, thus there is a need to ensure that this is actually the case, i.e. they are not used at an unnecessarily high frequency and that they are actually less costly than reliance on fumigation alone.

Financial constraints are not the only incentives for ensuring that fumigations are done well and not done more frequently than really necessary. Two other major concerns have appeared in the last 10 years and relate to problems with the use of the fumigant gases themselves. For more than 50 years, fumigation has been the major technique for destroying insects infesting grain and other durable commodities. However, over the years the number of gases employed for fumigation has steadily declined so that at the time of writing only two, phosphine and methyl bromide, are in regular use world-wide. Methyl bromide is now known to present environmental problems. In 1992, methyl bromide was listed in the Montreal Protocol as a chemical capable of depleting stratospheric ozone (Andersen and Lee-Bapty, 1992) and there are strong possibilities that its use will be severely restricted in the future and may eventually be banned. However, certain applications where short treatment times are essential, including those for quarantine and pre-shipment fumigation, cannot at present be substituted with alternative chemicals (Taylor, 1994). The other fumigant, phosphine, now presents problems as insects are becoming more resistant to it. This has arisen due to poor application technique which has allowed some insect survival after phosphine exposure and promoted the development of resistance (Taylor, 1989). The only way to overcome this is to practise good technique. This is particularly important as phosphine is currently the only effective alternative to methyl bromide in those situations where there is sufficient time to allow gas exposure periods of 5 days or more.

It is clear that there are advantages in ensuring that fumigations and spray treatments are used both efficiently and cost-effectively. To achieve this requires good decision-making on the part of those responsible for pest management. Such decisions need to be based on reliable estimates of the insect threat posed to the stored rice.

INSECT PEST MONITORING

It has long been understood that a means of estimating the size of insect populations is a prerequisite to effective decision-making for pest control operations. However, for bag storage of milled rice, it was only during the 1980s that it became clear that the prevailing technique, which involved taking spear (trier) samples from a number of grain bags, was inadequate for this purpose (Hodges *et al.*, 1985). This is because very large numbers of samples are required to obtain population estimates with a good degree of precision, such as mean values with standard errors of ± 15%. The actual numbers of samples varies according to species, some species having more aggregated populations which require more samples to estimate than those with more dispersed populations (Table 1). The problem is further exacerbated by the fact that for timely rather than precipitous decision-making, insect populations need to be estimated when they are still relatively small; to obtain a reliable estimate of a small population requires much greater numbers of samples. For example, a reliable estimate of a population of *Tribolium castaneum* (Herbst) present in rice at 1.1 insects/kg would require 79 samples, but a population density of only 0.65 insects/kg requires 159 samples. Frequently, more than 100 samples are required and this workload is unacceptable under normal warehousing conditions.

A range of trapping devices was tested to find an effective means of pest monitoring in milled rice stores in Indonesia. Promising results were shown by a trap consisting of a plastic net bag, with 2 mm apertures, filled with brown (unpolished) rice. These traps are called 'bait-bags' and can be placed on the sides of a bag-stack. The apertures in the net allow access to insects attracted to the brown rice (Hodges *et al.*, 1985). Further study of the bait-bags showed that the catch in the bags gave a reliable estimate of the insect population of the bag-stack

Table 1 Numbers of spear samples taken from bagged milled rice required to give estimates of mean population of various insect species with a sampling precision of ± 15%

Insect species	Mean numbers/kg	Observed degree of aggregation (1/*k*)*	No. samples for 15% precision
Sitophilus zeamais	1.10	4.50	240
Tribolium castaneum	1.10	0.88	79
Oryzaephilus surinamensis	0.97	0.84	82
Ahasverus advena	1.01	4.06	224

Source: Hodges *et al.* (1985).

* *k* is the dispersion parameter of a fitted negative binomial distribution, higher values of 1/*k* signify more aggregated pest populations.

as a whole and Haines *et al.* (1991) were able to construct calibration curves relating bait-bag catches to insect numbers/kg in bags of grain.

To use the bait-bag system to estimate insect populations on bag-stacks in the range of 175–300 tonnes requires a minimum of 20 bait-bags to be placed on the sides of the stacks. The number of bait-bags may be reduced or increased pro rata according to tonnage (Haines and Rees, 1988). Users are advised not to monitor on very small or remaining fractions of stacks. The bait-bags are left in place on the sides of stacks for 7 days, after which they are removed and the insects that have accumulated in them counted.

COST EFFICIENCY OF INSECTICIDE SPRAYING

The decision to follow a particular course of pest management action needs to take into account the cost-effectiveness of the available alternatives (Longstaff, 1997). Thus, in attempting to develop an improved pest management strategy for milled rice stores it was essential to demonstrate that routine applications of residual insecticide give value for money. To do this a study was undertaken to test whether routine respraying of store surfaces with insecticide resulted in a delay to refumigation and whether the sum of the costs of routine spraying would be equal to or less than the cost of refumigation. The bait-bag insect monitoring system was used to follow the development of insect populations in rice stores sprayed with various formulations of insecticide or no insecticide at all (Hodges *et al.*, 1992). The study failed to show that routine spraying resulted in any measurable increase in the period between fumigations. It was, therefore, concluded that such spraying was not cost-effective and a recommendation made that pest management operations should be limited to fumigation and a single spray treatment. This spray treatment would be applied while the fumigation sheets were still in place in order to kill any insects in cracks or resting on store surfaces that would reinfest the stock as soon as the sheets are removed. These recommendations relate specifically to the situation in which the study was undertaken. However, the results of the study call into doubt the practice of routine insecticide applications in all stores in the tropics. In response to this finding, a recent bulletin on storage technology, published by the Food and Agriculture Organization of the United Nations (FAO) suggests that routine spraying has little value (FAO, 1994).

It was clear that an effective pest management strategy for milled rice storage could be built around fumigation without the need for routine insecticide spraying. Thus a computer-based FDSS was developed in collaboration with BULOG which needed only to focus on pest management with fumigation. The FDSS was designed to enable pest control managers operating in grain depots to:

(a) predict the ideal timing for the application of fumigation, according to agreed criteria; and

(b) determine whether or not the most recent fumigation treatment had been successful. This is determined by the rate that a treated stock is observed to become reinfested.

CONTROL OF FUMIGATION OPERATIONS

The FDSS operates on estimates of the size of an insect population in a store provided by the bait-bag monitoring system. In the case of milled rice stores the most common pest, and almost invariably the first to arrive after the initial fumigation of a new rice stock, is the beetle *Tribolium castaneum* (Herbst). Other important pest species, such as *Sitophilus* sp. or *Rhyzopertha dominica* (F.), may sometimes be found at the start of storage but do not generally become re-established if they are killed at the first fumigation (Haines and Rees, 1988). Consequently, *T. castaneum* was chosen as the 'marker' on which pest management decisions are taken. Once an estimate of the population size has been made, the numbers are entered into a computer program holding the FDSS software which is written in Turbo Pascal version 7.0. This software contains a population growth model for *T. castaneum* which can predict how many weeks in the future the estimated population of this pest will exceed a given size or threshold (expressed in numbers of *T. castaneum*/kg). The program reports to the user that the fumigation should be undertaken at the time that, or just before, the threshold is reached. The program also alerts the user as to whether the most recent fumigation was successful or unsuccessful. It does this by calculating the size of the insect population at 6 weeks after the last fumigation: if this exceeds the normal expectations of 2 insects/bait-bag by a substantial margin, then the fumigation is reported as unsuccessful.

The principles on which the FDSS operates are shown in Figure 2 and the steps to be taken by pest control operatives are detailed in Box 1.

Box 1 Operation of the Fumigation Decision Support System

Step 1 – Insect Monitoring

Monitor insects with bait-bag traps about 5–7 weeks after the last fumigation and at least 2 weeks after any insecticide spray treatment on bag-stack surfaces.

Insect numbers should be estimated on about half the stacks in a store. In most storage depots it may be convenient to monitor about two stores each week.

Step 2 – Predicting When to Fumigate

Enter the numbers for the beetle *Tribolium castaneum* into the computer program.

After the data are entered, a recommendation will be given for when the whole store should next be fumigated. This will be in the week before the insect population, in the most infested rice stack, reaches the insect number threshold. A statement will also be made about the success or failure of the last fumigation. A graph showing the predicted development of the insect population in relation to the pest control threshold can be displayed.

An estimate of weight loss in the whole rice store during the period between the last fumigation and the recommended future fumigation can be obtained and a graph displayed showing how this ratio will change as the insect population grows.

Step 3 – Taking Action on the Prediction

The FDSS provides store managers with the basis on which to make a decision on when to fumigate rice stocks.

Once a recommendation to fumigate has been obtained this must be discussed with the manager responsible for store logistics. The final decision on the fumigation timing will depend upon many factors but must include:

- the likely period for which the stock will remain in store
- planned store operations, including incoming grain stocks.

If the prediction indicates that the last fumigation was a failure then review the condition of the stock and make a decision on whether the contractor should be called to repeat the work.

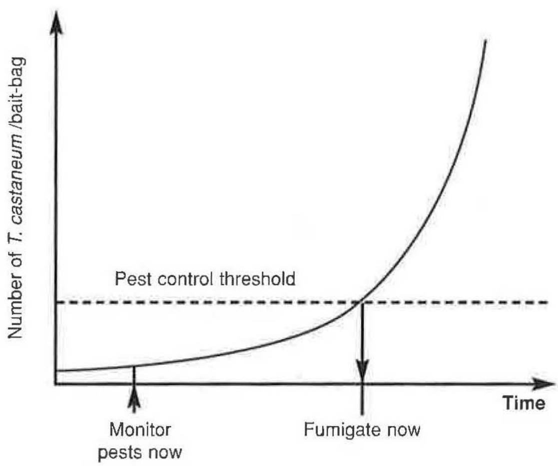

Figure 2 The operating principle of the Fumigation Decision Support System.

Insect growth model

Initially, a simple exponential curve was used to predict the population growth of *T. castaneum* but, following tests of the program, better results were found to be obtained from a logistic growth curve. This was fitted to data obtained from trials in East Java (Hodges *et al.,* 1992) in which the development of *T. castaneum* populations was monitored in a total of 6 stores and 12 bag-stacks, using both bait-bag traps and spear sampling (Figure 3). The logistic curve took the standard form:

$$N = \frac{im}{[i + (m-i)e^{-rt}]}$$

where N is population at time t, i is initial population (after fumigation), m is the maximum population the stack can support, e^r is the rate of population expansion, and t is time in weeks since fumigation.

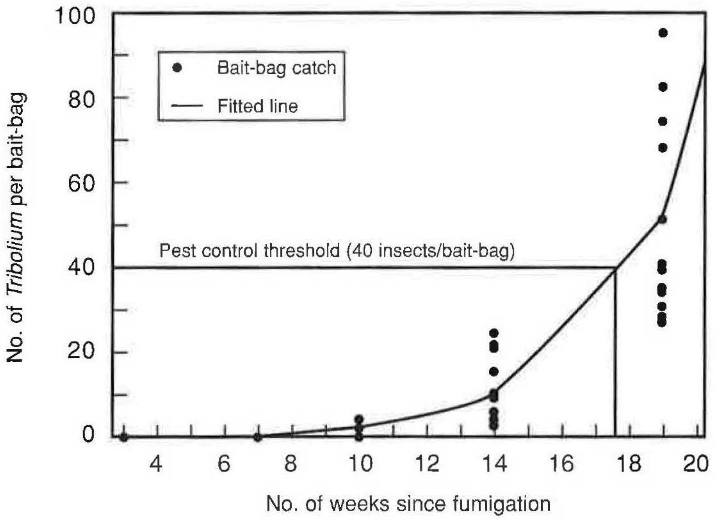

Figure 3 The logistic growth curve fitted to trial data.

The growth model was applied with no attempt to correct for variations in grain temperature, moisture content or rice milling degree. As the system was designed for use in the lowland tropics, conditions for all these variables were considered to be sufficiently constant to make such corrections unnecessary. The temperature close to the equator, inside stores, shows little annual variation. The range of both moisture content and milling degree of rice is subject to regulation, and although variable, is controlled within relatively narrow limits. Thus the FDSS is only valid for use in the lowland humid tropics where rice is stored in jute bags and is of a similar quality to that used in the study (e.g. moisture content 13.0–14.5%, milling degree 85–90%, broken grain 25–30%).

The growth model also takes no account of insects that migrate into a store once a breeding population has been established. The initial influx of insects following a successful fumigation is the major component of population growth. However, experience has shown that numbers migrating into the store soon become insignificant compared with those generated by a breeding population in the rice.

Pest control threshold

The pest control threshold used in the FDSS program is a pragmatic one. It is important that pest control is implemented before live insects in stores, and both live and dead insects in the rice itself, have a serious detrimental effect on the cleanliness of the store and the marketability of the rice. Therefore, it was decided that a threshold should be set to ensure that fumigation is undertaken well before the rate of population growth reaches its maximum. Examination of the model showed this to occur when the number of insects per bait-bag was around 150. At 40 *Tribolium* per bait-bag, population expansion is approximately half the maximum (Figure 3) which is about 10 insects/kg in the grain. This level of infestation is convenient in that it allows a reasonable lead time to fumigation, and so was selected as the pest control threshold. FDSS users can change this threshold to whatever level is convenient or appropriate to their system.

Whilst the pest management threshold used for the FDSS has a clear logical basis it does not address the issue of the cumulative effects of insect infestation such as contamination and weight loss that will occur over successive fumigations. One potentially serious contaminant is the quinone secretion of the thoracic and abdominal glands of adult *T. castaneum*. Quinones are mutagenic chemicals and the possibility of their accumulation in milled rice was investigated: however, no significant build-up could be detected (Hodges *et al.*, 1996a). There are facilities in the computer program to enable store managers to predict what milled rice weight losses might result from insects feeding in the period from the last fumigation up to the time that the next fumigation is recommended. These are based on weight loss estimates made by Halid (1988). However, no attempt has been made to use the financial value of potential rice weight losses compared with the cost of fumigation as a means of deciding whether or not pest control should be implemented. This is because before there are measurable weight losses, insect numbers will have become so high as to be unacceptable. The facility for weight loss calculation is only provided as a means of demonstrating that weight losses are small in comparison with the cost of fumigation, while rice contamination with insects and hence quality decline is relatively massive.

Validation of the FDSS

The FDSS was validated under warehouse conditions in Indonesia. An initial experimental trial was undertaken in a five-godown storage complex in West Java on 23 bag-stacks of milled rice, population estimates were made and the FDSS prediction based on these was checked by a second estimate at a later stage (Hodges *et al.*, 1996b). This demonstrated that the system had the potential to give accurate predictions of the time required to fumigation. Various growth models were tried but the exponential ($r = 0.39$) and logistic growth models performed better than the alternative models with 33% of predictions completely accurate. However, of the two models, the absolute mean deviation of the predictions for the logistic model was smaller (0.8 compared to 1.1 weeks), making it the preferred choice for use in the FDSS, although the exponential model would also be expected to perform well.

The experimental trial was followed by a 4-month operational trial in Central Java (Semarang) and West Java (Bandung). After a 2-day training course, Pest and Quality Control staff at Semarang and Bandung began insect monitoring 6 weeks after the first fumigation. At Semarang, initial insect numbers were so high, due to earlier fumigation failure, that bait-bag catches could not be counted in full. At Bandung, insects numbers in traps were within the normal post-fumigation range so an estimate could be made of the time to the next fumigation in two separate stores. To confirm the reliability of this prediction a second population estimate was made on the bag-stacks in the same stores 2 or 3 weeks after the first. The predicted fumigation intervals (period between the last fumigation and the recommended time for the next one) for each stack and for the stores as a whole are shown in Table 2. The results were remarkably consistent: of the 12 stacks studied, the fumigation intervals for 8 of these were the same on both occasions; of the other 4 only 1 differed by more than a week. It is recommended that all stacks in a store should be fumigated at the same time and that the time of fumigation is based on the recommendation for the most infested stack. This had the effect of reducing the fumigation interval in one store from 12 to 10 weeks, while the other store remained the same.

Potential financial advantage of using the FDSS

At the time of these studies at BULOG, fumigation treatments with phosphine or methyl bromide were applied, on a more-or-less calendar basis, every 3 months. Although various options for treatment meant that costs/godown varied, a typical cost for a full 3000-tonne store was US$ 2100 (1990 prices). On an annual basis, with a stock average of 1500 tonnes, the cost was about US$ 4400.

If the implementation of the FDSS causes only a modest reduction in the average annual frequency of fumigation, say an annual average reduced from four times to three and a half times, then the potential saving for a single godown would be about US$ 550. For a typical six-godown complex the saving would be US$ 3300. Set against this are the operating costs of the FDSS at the complex which amount to about US$ 900 annually. Thus the total saving would be US$ 2400. This does not take into account savings accruing from the detection of fumigation failures or any economic advantages in keeping stores cleaner and marketing rice contaminated with fewer insect remains.

Table 2 FDSS predictions of fumigation intervals* for godowns in Bandung based on two estimates of the same *T. castaneum* populations made at different times

Stack no.	Mean nos/ bait bag	Predicted fumigation interval	Mean nos/ bait bag	Predicted fumigation interval
Godown 4	**Week 6**		**Week 8**	
1	2.0	13	8.3	10
2	2.6	12	6.7	12
3	3.0	12	7.4	12
4	2.7	12	6.7	12
5	3.1	12	7.6	12
6	2.5	12	4.6	13
	Whole store fumigation interval = 12		Whole store fumigation interval = 10	
Godown 3	**Week 7**		**Week 11**	
1	4.0	12	20.7	12
2	3.2	13	16.3	13
3	4.8	12	24.0	12
4	3.3	12	17.0	12
5	3.3	12	17.0	13
6	3.4	12	17.5	13
	Whole store fumigation interval = 12		Whole store fumigation interval = 12	

* Number of weeks between the last fumigation and recommended time for the next fumigation.

CONCLUSION

The insect pest monitoring system using bait-bags, developed to support decision-making in milled rice stores, has been shown to give reliable estimates of insect populations in stores and has proved its value in demonstrating that routine applications of contact insecticide are not a cost-effective pest control option for milled rice stores. It is also an essential component for a decision-support system (FDSS) to help managers decide when their grain should be fumigated and if previous fumigations have been successful. Use of the system offers reductions in operational costs and ensures better value for money by highlighting when fumigation failure occurs. Such failures threaten to undermine the future of the fumigant phosphine by promoting insect resistance. A reduction in the fumigation failure rate will thus be an important contribution to maintaining the efficacy of this fumigant. This is especially important as the only alternative fumigant, methyl bromide, may soon be phased out.

The FDSS was specifically designed for use in Indonesian warehouses, but despite its advantages, to date it has not been introduced on a routine operational basis. The main reason for this is probably that the logistics of insect monitoring with bait-bags still presents a greater workload than is acceptable under normal operational conditions, despite the fact that it yields a reliable population estimate with far less effort than conventional spear sampling. Bait-bag monitoring works well but involves much more effort than subjective judgements on pest numbers or simply a calendar-based system of fumigation. If reliable estimates could be made of insect numbers using systems that require less effort, or in the case of automated systems, no effort, then the FDSS would be much better placed for uptake. An automatic insect monitoring technique for *T. castaneum* has been developed (Boon and Ho, 1991), which measures the weight of beetles captured in flight traps positioned in the store roof space. The weight of beetles is fed back to a computer at floor level which calculates the trap catch. This is a promising system and might one day be able to provide the FDSS with insect pest data. However, it still has to be demonstrated that it can fulfil two important prerequisites for management decision-making: first that the catch is proportional to the population in the bag-stacks and, second, that reliable catch data are available even when the population in the stored rice is still low, about 1 insect/kg, or preferably lower.

Even though the FDSS has not yet been adopted for operational use, it has been incorporated into a large expert system, called the 'Training Work Bench', devised in a project supported by the Australian Centre for International Agricultural Research (Longstaff, 1998). The purpose of the Work Bench is to train storage managers and their staff in effective operational procedures. The Work Bench offers the FDSS in a Windows format and enables staff to observe the growth of insect populations and learn how to set thresholds to determine when fumigation should be undertaken. The simulation is taken to its conclusion when the planned fumigation is integrated with other storage operations, particularly stock movements.

The FDSS, as it has been developed to date, is specifically for use in milled rice stored in jute bags in the lowland tropics and then only within a specified range of rice quality. Nevertheless, fumigation is applied to cereal stocks in many situations in the tropics and in many cases there would be substantial advantages if management control over fumigation could be brought to bear through the FDSS. The prospects for devising suitable pest monitoring systems and complementary FDSSs for other cereals in different tropical climates with different pest complexes is an open challenge. Further development of the pest control threshold would also be valuable. Quality deterioration across successive fumigations is an important issue, and predictions about the potential extent of contamination by dead bodies in relation to quality standards would be very useful information on which to base management decisions. However, the difficulties of achieving this should not be underestimated since market response to such quality determinants may be highly variable depending on supply and demand.

A copy of the FDSS software and instructions on its use can be requested from the Natural Resources Institute.

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Chapter 6

NEEDS ASSESSMENT IN POST-HARVEST RESEARCH AND DEVELOPMENT

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INTRODUCTION

In times of limited funding, it is important that research and development work in developing countries addresses constraints or opportunities that will have the maximum benefit on the livelihoods of those targeted by development organizations. In the post-harvest area, these beneficiaries range from farmers to final consumers and include those engaged in processing and trading. Research and development activities in the post-harvest area are complex in nature because of the interaction of technical constraints with the social and economic contexts of those involved. When research and development activities are undertaken, there needs to be a clear understanding of these complexities so that improved technologies will be adopted.

A common criticism of previous post-harvest research is that technical innovation has been high, but adoption has been poor. In many of these cases, the research and development agenda was usually decided on the basis of either formal questionnaires or site visits by scientists. These techniques are limited by the extent to which they involve the end-user in deciding what interventions need to be made.

This chapter draws on information from a UK Department for International Development (DFID) Regional Africa Project in which informal needs assessment techniques were adapted for use in post-harvest systems. To demonstrate the value of the approach, technology transfer activities were developed from survey findings in Tanzania, Uganda and Ghana. Needs assessment is a term used to describe a range of qualitative diagnostic methods such as rapid rural appraisal (RRA) and participatory rural appraisal (PRA) (Cropley and Gilling, 1993). Their essence is that they facilitate communication between scientists and farmers. The use of needs assessment can actively involve stakeholders in key phases of the project or research and development cycle when research priorities are set or technology choices are made. By ensuring the relevance of research and subsequent technical interventions, the prospects for adoption and, therefore, impact, are greatly improved.

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WHAT IS NEEDS ASSESSMENT?

Needs assessment is a term used to describe both an attitude and a range of techniques to identify constraints and opportunities. The attitude is non-formal, open minded and analytical. The techniques are participatory and the stakeholders are active participants in the process rather than just respondents.

In the early 1980s, the RRA approach to initial project preparation was developed. RRA was defined (Conway, 1986) as "a systematic, but semi-structured activity carried out in the field by a multidisciplinary team designed to acquire information rapidly on, and hypotheses about, rural life". Essentially, RRA is an approach that relies on semi-structured interviews and visual techniques such as mapping and ranking. While recognizing the need to understand problems and constraints in the context of prevailing socio-economic conditions, RRA tended to be extractive with analysis of constraints and research priorities undertaken by the team of experts.

PRA evolved from RRA approaches with emphasis being given to interactive (or participatory) methods of problem diagnosis and approaches to resolving them. Chambers (1992) gives a detailed account of the way in which methods have evolved. An important concept behind PRA is that rural communities have a contribution to make to the process of identifying and prioritizing their constraints and aspirations and to the planning and implementation of ways of solving constraints or achieving development objectives. Participatory needs assessment uses elements of both RRA and PRA in a diagnostic fashion to prioritize technical research or to assist in technical choice. Some of the key features of needs assessment are set out in Table 1. Overviews of participatory research approaches are given by Chambers (1992) and Chambers and Ghildyal (1985).

PLANNING AND CONDUCTING AN INFORMAL NEEDS ASSESSMENT STUDY

Objectives

Deciding on the objectives is one of the most important parts of survey planning (Gilling and Cropley, 1993). The objectives of the study will determine which tools and techniques should be used. RRA and PRA are less structured than formal questionnaire surveys and often decisions on who to interview, and on which subjects, are taken spontaneously in the field. If the objectives are not clear beforehand, the study may suffer from unfocused, arbitrary questioning and result in weak conclusions and a failure to investigate key areas.

Team composition

Survey team composition is key to the success of a study. Unlike formal surveys, where relatively unskilled workers can be trained as enumerators, informal

Table 1 Key features of informal needs assessment approaches

Feature	Comments
Triangulation	In informal needs assessment the same information is collected from several different perspectives as a means of confirming observations; this is called triangulation. In the absence of extensive sampling, it assists in checking the validity of the information and improves accuracy.
Flexibility	Flexibility occurs in two ways: (1) researchers can change the techniques or questions during the investigation because as much is learned during data collection as at the final stage of analysis, and (2) in the absence of a standard protocol, there is freedom to combine methods to suit a particular occasion.
Multidisciplinary teamwork	Farmers operate in complex environments. A research team with a number of different appropriate disciplines is in a better position to understand all aspects of a situation.
Serendipity	Serendipity is recognizing or creating opportunities in which the researcher can take advantage of chance. For example, a researcher can pursue a different line of enquiry in response to an interesting individual or an unexpected situation.
Investigating exceptions	The following-up of exceptions and lack of agreement is an important principle of needs assessment. It can lead to an understanding of why only certain parts of the population undertake a certain activity such as processing or storage.
Participation	Participation of beneficiaries in data collection and analysis is the key to needs assessment. It facilitates ownership of project activities as they are developed and it ensures that interventions address the problems and opportunities facing the target population.

Source: Adapted from Kleih *et al.* (1997); Theis and Grady (1991); Conway (1986).

surveys require technical specialists with open and enquiring minds. At least one team member should be experienced in planning and conducting a survey. The members of the team should have different skills and backgrounds so that their viewpoints will complement each other and provide a more comprehensive picture. The nature and objectives of the survey will determine which disciplines are required. As small a team size as possible should be used to ensure minimal disruption in the selected area. If large numbers of people are involved in a survey, it is often best to divide them up into smaller groups with regular interchange of personnel between groups. Sufficient time should be allowed for team training and the pre-testing of the approach.

Site selection

Appropriate decisions at the site selection stage will determine the quality of information collected. It is particularly important to consider the significance of bias when selecting sites. For example, survey teams have been criticized in the past for selecting sites that are close to roads and are easily reached in the dry season. Stratification is often used in site selection. It is a means of improving sampling efficiency by dividing the population into sub-sets within which the variability of key factors is expected to be lower. A typical example is agro-ecological zoning by which an area is divided into sub-sets based on homogeneity of rainfall, farming system or even crop yields. The success of stratification depends on the quality of the data on which it is based. Well chosen stratification strategies can help to ensure that perceived linkages between key variables can be investigated in the most effective manner. If the sample has not been formally stratified at the planning stage, appropriate adjustments could be made in the field. However, if the sample has been randomly selected, any adjustments would negate the results if they were used for generalizing about the population.

Time considerations

Four important time factors need to be considered when planning a needs assessment study:

- overall time availability
- time allocation to each stage of the survey
- timing of the actual survey
- duration of interviews.

A minimum of 6–8 weeks should be allocated for a successful survey depending on the nature of the issue being considered and the experience of the survey team. This should be divided up as 1–2 weeks on preparation, 4 weeks carrying out the field work and 3 weeks preparing reports. The timing of the survey needs some knowledge of the locality to be visited. The length of individual interviews will vary considerably according to local circumstances, language skills, individual characters and experience in informal survey methods. The survey team is generally responsible for judging when an interview is becoming too long for the participants.

Sufficient time should be allowed for discussion of results amongst team members and report writing. It is important to establish the exact procedures for note-taking during interviews prior to the survey starting so as to avoid losing information. It is also important to prepare a draft report whilst the information is still fresh in people's minds. Good quality reporting is essential to give decision-makers the correct impression.

NEEDS ASSESSMENT TOOLS AND TECHNIQUES

There are a range of tools and techniques that can be used in a needs assessment study and these are briefly outlined below. The descriptions given below are based on those described in Kleih *et al.* (1997) and are adapted from Theis and Grady (1991). It is not necessary, or even in many cases desirable, to use all of the tools in all circumstances. The tools should only be used as means to facilitate a dialogue between researchers and stakeholders. As in all good research, hypothesis formulation and testing are central and take place through an iterative process of discussion and explanation. The most common tools used are review of secondary data, direct observation and semi-structured interviewing.

Review of information from secondary sources

The review of previous studies and other secondary sources can improve the efficiency of a study by:

- avoiding gathering the same information twice
- increasing the ability to explain certain observations
- allowing researchers to select sites and identify variables in advance
- allowing researchers to put their findings into context
- allowing historical data to be used in conjunction with contemporary studies.

Secondary information relevant to the area or subject of the planned study may be either published or unpublished and include reports, statistics, maps, aerial photographs or films. These should be reviewed before beginning the fieldwork and should be prepared as diagrams, tables and lists, brief summary paragraphs or copies of photographs and maps.

In reviewing secondary information, it is important to be sceptical and critical and identify what information is missing. It may be possible to develop hypotheses to be tested in the fieldwork as a result of reviewing secondary data.

Direct observation

Needs assessment relies to a large extent on interviews with individuals and groups. One of the main dangers is that it is possible to be misled by myth, rumour or gossip. Direct observation of key events or indicators provides a means of supporting and cross-checking key findings. These indicators or events include: weights and prices in the market, processing methods, storage techniques, etc.

Semi-structured interviewing

Semi-structured interviewing is one of the main tools used in needs assessment. It is a form of guided interviewing where only some of the questions are predetermined and new questions are introduced during the interview. At most, informal needs assessment uses a checklist of questions as a flexible guide rather than a formal questionnaire. Semi-structured interviews generally take the form of a discussion where interviewer and interviewee learn from each other. They often form the basis for the introduction of other needs assessment tools such as ranking or scoring.

There are four main types of semi-structured interviews, individual, key informant, group and focus group. All may be necessary during the course of a needs assessment study.

Individual interviews are used to extract representative information. In comparison with interviews with groups, it is more likely to reveal conflicts in the community as respondents will speak more freely than with their neighbours present. An opportunity sample of purposively selected individual respondents is taken. Such a sample of farmers might include farmer leaders, innovative farmers who have tried new techniques, women farmers who are both heads and members of households, poor farmers and traditional farmers who have resisted technological change. Gender bias must be avoided and interviews should focus on respondents own practice and knowledge.

Key informant interviews are used to obtain information specialist information. A key informant is anyone with special knowledge of a particular topic, for example, an extension agent on cropping practices, a bank employee on credit practices, etc. Key informants are expected to be able to answer questions on the knowledge and behaviour of others and especially about the operation of the broader system. Although it is necessary to cross-check information, key informants are often important interviewees.

Group interviews are used to obtain information at the community level. They allow access to a larger body of knowledge and provide an immediate cross-check for information as it is received from others in the group. They are not useful when sensitive issues are being discussed. Interviews should encourage the expression of alternative views and opinions.

Focus group discussions enable the discussion of a particular topic in detail. A small group of people (6–12) who are knowledgeable about, or interested in, a particular topic, is invited to participate in a discussion. A facilitator is used to ensure that the discussion does not digress too far from the original topic and that one participant dominates the discussion.

Guidelines for undertaking semi-structured interviews are given in Kleih *et al.* (1997).

Ranking

Analytical tools such as ranking complement semi-structured interviewing by generating basic information that leads to more direct questioning. They may be used either separately or as part of an interview. Pairwise ranking, for example, helps to identify the main problems or preferences of individual community members and their ranking criteria. It enables the priorities of different individuals to be easily compared. Ranking is useful for sensitive information, particularly about income levels. Informants tend to be more willing to provide relative values rather than absolute figures.

There are a range of ranking methods available including verbal ranking, preference ranking (ranking by voting), pairwise ranking, direct matrix ranking and wealth ranking. Examples of the use of these methods in non-grain starch staple post-harvest systems are given by Kleih *et al.* (1997).

Scoring

Scoring exercises allow needs, priorities, etc., to be placed in order of importance and provide evidence of the weight accorded to them. Although a simple ranking exercise may reveal that, for example, processing constraints are more important to farmers than storage constraints, it will not allow an exact comparison.

There are three main scoring methods:

- verbal scoring
- list scoring, for example, scoring all the constraints in the farming system
- matrix scoring, for example, scoring three alternative storage systems against a number of criteria.

Diagrams

Diagrams provide a means of presenting information in a condensed and readily understandable form. They are useful at all stages of a needs assessment study: planning, field discussions and analysis. The act of constructing them is an analytical process that facilitates communication and stimulates discussion. There are various types of diagram as summarized in Table 2.

Table 2 Types of diagrams used in needs assessment

Concept being investigated	Type of diagram
Space	Map, transect
Time	Seasonal calendar, daily routine chart, time trends, historical profile
Relations	Flow diagrams, livelihood analysis, systems diagram
Decisions	Decision tree, Venn diagram

Case studies

Although not a data collection technique as such, case studies are often useful for illustrating complex issues, particularly when large amounts of information are being summarized.

ISSUES TO CONSIDER IN USING NEEDS ASSESSMENT

There are several dangers and shortcomings that can be associated with informal data collection (Kleih *et al.*, 1997). Many of these can be overcome by the survey team provided that it is aware that they can exist.

Needs assessment studies must be well planned. The objectives of the study must be clear and there must be adequate use of secondary data. Time schedules for planning and implementation must be neither too long nor too rigid. The team(s) should have a balanced composition (including both natural and social scientists) and not be too large. Biases in site and population selection must be avoided.

The individual tools must not become ends in their own right. Open questioning techniques are required and generalizations based on inadequate information or from too few informants must be avoided. The expectations of the community should not be raised above that which can be delivered. Sufficient time has to be allowed at each stage to avoid superficiality and a lack of participation of the potential beneficiaries.

Data collected using informal survey methods can rarely be tested using statistical methods, because random sampling plans for locations and informants are not usually used. Information should be obtained from several sources to ensure that it is valid.

Needs assessment studies require the allocation of adequate resources. In comparison to a formal survey they usually require experienced and often more senior staff to undertake fieldwork. All forms of survey are costly, but needs assessment, carried out well, offers the potential to generate workable conclusions relatively quickly.

The needs assessment approach is an attempt to bridge the gap between researchers and stakeholders. Various institutional issues can affect this relationship and this can impact on the use of the method. Hall and Nahdy (1999) investigated some of these issues in DFID-funded research in Uganda. These issues include professional identity, skills provided by higher education institutions, professional reward systems, the perceived validity of research undertaken with informal survey methods and the problems of constraints being identified which are beyond the scope of the particular institutions involved.

THE CASES FOR AND AGAINST NEEDS ASSESSMENT

The alternatives to informal needs assessment, as mentioned above, are structured sample surveys based on questionnaires and visits to farms, processing sites and markets by specialist scientists followed by workshops and technical message formulation meetings at research institutes. The cases for and against informal needs assessment were evaluated by Marsland and Bockett (1997) and these are summarized below.

Speed

Needs assessment studies can generally be planned, trained for, executed and written up over a shorter timeframe than conventional formal sample surveys. Their superior speed is particularly apparent in the execution and report writing stages. Problems with speed can, however, occur when, for example, difficulties arise at the stage of analysis when the complexity and wealth of often non-quantifiable data make it difficult to draw out analytical threads.

Cost and logistics

In addition to speed, needs assessment exercises can be cheaper than sample surveys. Characteristically, they pose fewer logistical problems. This is because they can be executed by small mobile teams that combine the functions of data collection and a certain amount of analysis and writing up. On the other hand, whilst needs assessment may be cheaper in the field, this needs to be balanced against potentially high training costs. Moreover, needs assessment is more likely than sample surveys or site visits to require external assistance.

Technology fit

Needs assessment is seen as a particularly appropriate start to the research process in areas and environments that are complex, diverse and risky, such as the rainfed tropics, hinterlands, hills, swamps (Pretty and Chambers, 1993; Sumberg and Okali, 1988). The physical conditions of these farmers are difficult to capture *ex ante* through a pre-determined questionnaire, and a necessary holistic understanding may easily elude even the most experienced scientist on a village visit. In such circumstances, an approach that combines a farming systems perspective, using multidisciplinary teams, with analytical rigour and flexibility offers clear attractions for the researcher. Needs assessment offers the potential for more meaningful dialogue with communities than formal surveys and site visits. For this reason, needs assessment reduces the likelihood of what Chambers (1983) has termed 'professional bias'. The logical outcome of a more appropriate constraints diagnosis process is more appropriate technology, measured by adoption rates. Good examples of this are cited by Rhoades and Booth (1982) and Bockett (1997).

Giving a voice to the poor

With the combination of attitudes and techniques, needs assessment holds out the prospect for a more meaningful dialogue with resource-poor farmers, women and other less advantaged groups within the community than either sample surveys or site visits. By promoting increased contact between researchers and poor communities, needs assessment should reduce the likelihood of the researcher basing research on preconceived ideas.

Scientific methods/content

It can be argued that needs assessment, despite its origins in anthropology and 'soft' social science, contains important elements of science. One of these is hypothesis formulation and testing. Even the most ardent sceptics of needs assessment would be forced to admit that the methodology is well suited to generating testable hypotheses. What is less clear is whether needs assessment is up to the task of rigorously testing hypotheses. This is related to the issue of generalizing the results from needs assessment, which in turn is related to representativeness. With careful use of secondary data, and sensible planning, needs assessment exercises can take place in sites that are broadly representative of wider areas. Within villages, random sampling can be used to select different households. Techniques, such as wealth ranking, have been demonstrated to deliver useful socio-economic strata from which to sample. Within village representativeness is also achieved through triangulation (Table 1), to ensure that an accurate picture of farming constraints has been gained. In response to the criticism that needs assessment may create data but is not susceptible to statistical analysis, proponents argue that techniques are available to analyse the sorts of unbalanced, binary, categorical and ranked data often generated by needs assessment (e.g. Martin and Sherington, 1997).

This said, without a properly delineated sample frame and random sampling, it is difficult to gain a sample from which to generalize. Site selection will, therefore, be biased to some degree, and important segments of the population can be missed. In their attempts to present 'hard' data, needs assessment studies sometimes generate numbers that can be short on analytical content and which cannot be generalized. These issues pose questions over whether the needs identified have any validity outside the specific villages or households where needs assessment takes place. It has been suggested that short focused questionnaire-type surveys may be used to complement typical needs assessment data.

Links to the research process

Another argument in favour of needs assessment is that it is an appropriate start to a relationship of collaboration with farmers throughout the research process. Through interacting with farming communities during the diagnosis stage, needs assessment, more than sample surveys or site visits, prepares the way for more participative forms of research.

EXAMPLES OF RESEARCH OR DEVELOPMENT ACTIVITIES DEVELOPED FROM NEEDS ASSESSMENT STUDIES

With support from DFID, the informal needs assessment approach was validated in collaboration with national programmes in Ghana, Tanzania and Uganda. Four major studies were carried out over a period of 2 years. During the studies, the technique was adapted to post-harvest systems. On the basis of the outcome of the studies a number of technology transfer activities were undertaken to address the constraints or opportunities identified. The studies are summarized in Table 3.

Table 3 Needs assessment studies and technical interventions made in sub-Saharan Africa

Needs assessment study	Major constraint or opportunity identified	Technology transfer/ research projects initiated	References
Study of post-harvest problems of non-grain starches staples in five regions of Ghana (1)	Lack of market opportunities for cassava	Use of dried cassava chips in livestock rations (3)	(1) Kleih *et al.* (1994) (2) Hector *et al.* (1996) (3) Hector *et al.* (1997)
Urban demand/needs assessment study in Dar es Salaam (4)	Losses during marketing of fresh cassava	Adaptation of low cost cassava storage technique (5)	(4) Ndunguru *et al.* (1994) (5) Ndunguru *et al.* (1998)
Collaborative study with Cassava Biotechnology Network in Lake Zone, Tanzania (6)	Requirement of women to access new markets with cassava	Product diversification for women (7)	(6) Thro *et al.* (1994) (7) Kapinga *et al.* (1998)
Analysis of sweet potato post-harvest systems in Uganda (8)	Food security in the dry season caused by perishability of fresh root and inability to store in ground	Pit and clamp storage techniques introduced (8,9)	(8) Hall *et al.* (1998) (9) Bockett (1996)

Two of the studies are presented in more detail below.

Post-harvest constraints and opportunities in Ghana

The needs assessment study

A needs assessment study was carried out in the Brong Ahafo, Central, Eastern, Ashanti and Western Regions. The study was carried out in late 1994 and took 6 weeks to complete. The main tools used were semi-structured interviews using checklists, scoring and ranking exercises. The survey comprised 20 group meetings with farmers, 6 meetings with processors and about 40 meetings with traders. The major commodities considered were cassava, yam, cocoyam and plantain.

Farmers expressed their needs in the following order: financial constraints, high costs and unavailability of inputs, transport problems, low commodity prices, crop diseases and pests, lack of processing equipment, high labour costs, late maturing varieties, no sheds in the market, heat and smoke during processing and land tenure/scarcity of land. Other less important constraints were also mentioned (Table 4).

Table 4 Summary of needs expressed by farmers in 20 villages in Ghana determined using a scoring technique

Constraints	Score (out of 1940)
Financial constraints	590
High costs and unavailability of inputs	281
Transport problems (lack of infrastructure and vehicles)	256
Low commodity prices	131
Crop diseases and pests	128
Lack of gari processing equipment	112
High labour costs	85
Storage (lack of facilities and technologies)	68
Late maturing varieties	50
No sheds in the market	44
Heat and smoke during gari processing	36
Land tenure / scarcity of land	36
Lack of yam staking material	29
No credit sales for inputs	28
Weeds	27
No scales in the market	20
Others (erratic rainfall, deforestation, no markers, no fixed input prices)	19

Source: Adapted from Kleih *et al.* (1994).

Farmers consider the prices that they obtain for fresh or processed products to be too low (Table 4). A diversification of outlets for cassava is likely to lead to increased demand for cassava products which in turn should result in upward pressure on prices. This approach should also be seen in the context of farmers' financial constraints. Increased production for markets is likely, on the one side, to reduce cash constraints and on the other side to be a condition for obtaining credit. Some farmers had already identified crop processing as a means of increasing income through existing or new marketing channels; examples of successes include processing of the traditional products, *gari* and *agbelima,* and the recently introduced production of chips for export to the European Union.

The technical intervention

As a result of the needs assessment study it was suggested that markets for dried cassava as a substitute for maize in the local feeds sector should be investigated. The opportunity has been developed under a participatory technology transfer programme involving smallholder farmers, the animal feeds sector and small-scale livestock producers.

Participatory programmes were implemented with cassava farmers to develop a high quality product that can be integrated into the current feeding system. Quality is maintained through the control exerted by the production system – a combination of mini-chipping and sun-drying protocols combining elevated trays and black groundsheets (Hector *et al.,* 1996). Chip production is possible from October to late March, after which labour must be allocated to yam production.

The stability of the dried product has been evaluated under working conditions in partnership with the animal feed sector, where the mini-chipped product satisfies their storage requirements (high resistance to insect attack, low dust generation). Current milling was used to produce a granular end-product (Hector *et al.,* 1997). The feeding value of this product is being assessed by testing it at various levels in broiler, layer and pig grower rations in participatory programmes with small and large-scale poultry, egg and pig producers.

The final stage of the programme consists of dissemination, extending chip production to identified customers and selecting and evaluating longer term production strategies in relation to the value of cassava and livestock products.

The need for fresh cassava storage in Tanzania

The needs assessment study

A needs assessment study was used to identify problems and opportunities in the marketing chains for fresh cassava roots entering Dar es Salaam from villages in Pwani and Tanga Regions (Ndunguru *et al.,* 1994). The main techniques used were market chain analysis (identification of marketing chains from urban markets back to production) and semi-structured interviewing. The marketing chain was complex (Figure 1). Emphasis was placed on individual and group interviews at key stages in the marketing chain. The number of interviews with each class of participant in the marketing chain was judged on the basis of ensuring the information obtained was consistent.

The major constraints identified within the system were delays in the marketing chain for fresh cassava which caused physical and economic losses. Time delays

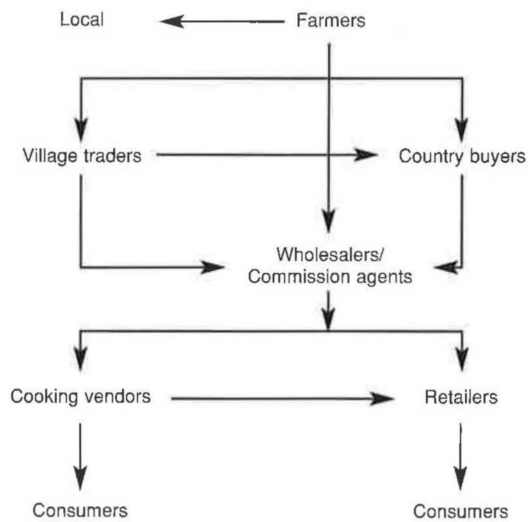

Figure 1 Market chain for fresh cassava from rural areas into Dar es Salaam, Tanzania. *Source*: Ndunguru *et al.* (1994).

Table 5 Time-related value changes for fresh cassava at different stages in the marketing chain from Kisarawe district to Dar es Salaam market, Tanzania

Stage of marketing chain	Storage time	Price per unit (TShs) (pieces per fixed price at retailer level)	% discount
Farmer	'Fresh'	2000	
	2 days	1500	25%
	3 days	1000	50%
	>3 days	<500	>70%
Country buyer	'Fresh'	4500–5000	
	2–3 days	500–1000	80%
	>3 days	<500	>90%
Wholesaler	'Fresh'	6000–7000	
	2–3 days	1500–2000	75%
	>3 days	600–1000	90%
Retailer	'Fresh'	3–5 pieces (30 TShs)	
	2–days	5–6 pieces (30 TShs)	up to 50%
	>3 days	negotiable	

Source: Ndunguru *et al.* (1994).

were an important factor in determining the level of price discounting (Table 5). At some stages in the marketing chain, economic losses were greater than 90% of the initial value. It became clear during the study that the main players in the market chain did not perceive quality or reduced shelf-life as important issues.

They were purely concerned with economic losses associated with cassava marketing. This point of view was taken into account when developing a strategy for disseminating an appropriate technology.

The technical intervention

Technology transfer activities were initiated using elements of a low cost cassava storage technology (Bancroft and Crentsil, 1995). This technique involves grading, trimming and exposing fresh roots to conditions of high humidity (such as washing and placing in a polyethylene sack). These conditions delay natural physiological deterioration. The various elements of the technology showed significant beneficial effects relative to traditional marketing practices. Trials conducted in markets in Dar es Salaam and villages in Pwani Region that supply the markets demonstrated that low cost cassava storage technology can maintain the quality and freshness of cassava for 7–10 days, compared with 1–2 days using conventional techniques. Supporting economic studies (Ndunguru *et al.*, 1998) demonstrated the economic benefits of adoption of the technology. Market commission agents and representatives of village governments agreed that the technology should be disseminated throughout the market chain with initial emphasis being placed at the level of farmers and country buyers.

A participatory approach was used to develop a dissemination strategy for fresh cassava storage technology. The approach proved useful as it involved key players from the market chain in identifying the best approach for dissemination, the development of suitable supporting materials (leaflets and posters) and in carrying out training activities with minimal support from project personnel. It was also possible to ensure that a clear link was established in the minds of potential beneficiaries between the technology and improved incomes from cassava marketing.

Impact assessments made during the course of the dissemination process showed that peoples' commitment to the uptake of the technology was closely linked to their appreciation of its practical benefits. In the later stages of the project, the level of understanding of the technology had increased to the point where the village governments and market co-operatives had assumed ownership of the technology and were collaborating together to promote uptake within the market chains. Particularly encouraging was the introduction of new bylaws for fresh cassava trading following discussions between a number of village governments in Pwani Region and representatives of the market co-operatives in Dar es Salaam. In addition several village governments had initiated their own training schemes to disseminate the technology to local farmers and cassava traders using village funds.

Lessons from case studies

The above studies have shown how needs assessment surveys can be used as a starting point for research or technology transfer activities. Each of the needs assessment studies was completed in a short amount of time and enabled the technology transfer activities to start with a minimum of delay. Links with stakeholders in the production and marketing systems were developed during the needs assessment studies and these proved valuable in the subsequent technology transfer activities.

The examples detailed above do not in themselves provide definitive proof of the success of the needs assessment approach because there was no direct comparison with other approaches (such as the use of formal questionnaire surveys). This said, it is difficult to visualize how formal survey methods would have been able to analyse the relatively complex situations in each of the case studies and recommend technologies that would have immediate benefit.

CONCLUSION

Informal needs assessment, as a tool for use as part of the project cycle, offers the potential to improve the impact achieved by research and development activities in the post-harvest sector. Care is, however, needed in the use of the approach as it can potentially have a number of methodological and institutional shortcomings. Many of the methodological issues can be overcome through experience and training.

Needs assessment, based on PRA and RRA, is still a relatively new approach in the post-harvest area. Whilst it is true that needs assessment can be a powerful tool for diagnosis of researchable constraints in complex environments, it can sometimes fail to live up to its potential. Moreover, even where constraints are correctly diagnosed, that in itself is not enough to ensure that solutions that will be willingly adopted can be found. The case studies given in this chapter do, however. show how the approach has been successfully used to orient technical interventions. Finally, needs assessment is not a panacea. It has risen to prominence partly if not largely because of perceived shortcomings in the existing alternatives. Researchers were looking for better answers, and thus some have seized on needs assessment with perhaps more alacrity than was, in retrospect, prudent. It is proposed here that needs assessment has its place, and it is an important element in the repertoire of diagnostic techniques open to researchers.

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Chapter 7

HAZARD ANALYSIS CRITICAL CONTROL POINT (HACCP): FROM THE FARM TO THE FORK

Linda Nicolaides

INTRODUCTION

Hazard Analysis Critical Control Point (HACCP) is a system used by the food industry to ensure that all food consumed is safe to eat. HACCP is a systematic approach to hazard identification, assessment of risk and control. It is a structured approach for the control of food safety from the farm to the fork. The concept of HACCP was first introduced during the mid 1960s when a reliable method for manufacturing pathogen-free food was required by the US space programme.

The HACCP concept has been successfully applied in the control of safety in low-acid canned foods in the USA, and many food companies in Europe and the USA have adopted the approach. Increasingly, regulatory bodies have recognized the usefulness of this tool and its principles have been incorporated into legislative requirements by both the European Union, the General Hygiene regulations for managing food safety (93/43/EEC), and the US Food and Drug Administration (USFDA) (CPR-123).

Until the introduction of HACCP, end-product testing was used as a means of assessing food safety, i.e., a percentage of samples was tested to find out if the product met with the customer's acceptance criteria. Tests included microbiological testing, chemical and biochemical analyses, measurements of physical properties and sensory evaluations. However, a number of limitations to this approach have been recognized. For example, sampling plans are based on the probability of a fault being identified through testing a representative number of samples, to check that the end-product conforms to the standard. In reality, if a process is not working properly and sub-standard product is being manufactured, the cause of the problem may not be identified until several days after the fault has occurred. Many of the microbiological tests used to demonstrate that a food is safe to eat require 3–5 days incubation before results are available to prevent hazards occurring. This has resulted in financial losses to the food industry when a product has to be recalled or, in the worst scenario, a consumer has contracted food poisoning as a result of eating an unsafe product.

The HACCP approach to food safety moves away from testing the final product, and instead emphasizes the raw material and process control. Control is taken out of the laboratory and into the processing environment. HACCP provides a

Box 1 Definition of terms

Concern – an expert judgement on the level of threat to the consumer of a particular hazard:

- high concern – if the hazard is not controlled there is a life threatening risk
- medium concern – a threat exists to the consumer that must be controlled
- low concern – little threat exists to the consumer, however, it should preferably be controlled
- no concern – no threat exists to the consumer.

Control – to take all necessary actions to ensure and maintain compliance with criteria in the HACCP plan.

Control measure – any action and activity that can be used to prevent or eliminate a food safety hazard or reduce it to an acceptable level.

Corrective action – any action taken when the result of monitoring at the critical control point (CCP) indicates a loss of control.

Critical control point (CCP) – a location, practice, operation, stage or raw material at which control can be exerted to eliminate, prevent or reduce a hazard to an acceptable level.

Hazard – a biological, chemical or physical agent in, or a condition of, food with potential to cause harm to the consumer.

Severity – the seriousness of the hazard.

Risk – probability of the hazard occurring.

structured and systematic approach to the control of identified hazards, which may be biological (microbiological), chemical, physical or a combination of the three. A critical control point (CCP) is a raw material, stage, practice or operation within the process where a hazard has been recognized and steps are in place to eliminate, prevent or reduce the possibility of the hazard occurring. This and other definitions are included in Box 1.

There are seven principles incorporated into the HACCP system (Codex Alimentarius, 1997):

1. Conduct a hazard analysis.
   Identification and description of the product and its intended use. Assessment of hazards and assessment of risks associated with all stages and practices of product handling and processing.

2. Determine the CCPs that will eliminate or minimize the risk.

3. Establish critical limits.

4. Establish a monitoring system to demonstrate that the CCP is under control.

5. Establish a procedure for corrective action when the CCP is seen to be moving out of control.

6. Introduce verification procedures to confirm the effectiveness of the HACCP plan.

7. Establish documentation and records to demonstrate that the HACCP system is working effectively.

A thorough understanding of the whole process is required in order to identify the most appropriate means of monitoring CCPs. Tests where results are obtained quickly are preferable to traditional lengthy microbiological methods, for example, measurement of pH level instead of counting for bacteria that produce acid, whilst for other stages visual or sensory evaluation may be required, for example, colour and odour of wet fish. It is, therefore, important to assemble a team of specialists that can look at the whole process from the point of view of their own area of expertise, and who can contribute to the overall HACCP study.

Food safety has been the principal aim when applying the HACCP concept to a process. The technique was originally developed for control of microbiological hazards but it can just as easily be applied to other areas such as chemical contaminants and some foreign bodies.

There are a number of factors outside the control of handlers and processors that can affect the safety of food. For example, in the production of vegetables, the site of the production unit can range from large mechanized farms to smallholdings. Different cultivars have been bred for yield, disease resistance, etc. Hazardous practices, such as the use of raw sewage as fertilizer, or allowing animals which carry bacteria, viruses and parasites, to forage amongst crops, together with inadequate processing and storage facilities, may increase food safety risks associated with the products. These and other factors must be considered when planning safe management systems.

An HACCP study is carried out in four stages: defining the scope of the study, implementing the study, verifying and maintaining the system. It is important to establish the scope of the study, i.e. the area to be addressed by the HACCP plan – from the farm supplier of raw materials through to the retail outlet or consumer. It is also paramount that management are fully supportive of the implementation of HACCP, especially where financial investments are concerned.

DEVELOPING AN HACCP PLAN

This chapter can be used as an aid for those responsible for implementing and maintaining an system. Its scope might cover all parts of the production/growing stage of the commodity, any subsequent handling, processing or packaging of the product, as well as distribution, catering, retail and consumer handling. A flow diagram of the logical sequence for implementing HACCP is shown in Figure 1.

Assemble an HACCP team

↓

Describe product

↓

Define essential characteristics
of the product and intended use

↓

Construct a process flow diagram

↓

On-site verification of process flow diagram

↓

List all potential hazards
Conduct a hazard analysis
Determine control measures

↓

Determine CCPs, assess level of concern

↓

Establish critical limit for each CCP

↓

Establish a monitoring system for each CCP

↓

Establish corrective action for deviations that may occur

↓

Establish verification procedures

↓

Establish record keeping and documentation

Figure 1 Stages in developing an HACCP system. *Source*: Based on WHO/FNU/FOS/95.7.

Stage 1 – the HACCP team

To fully understand the process and be able to identify all likely hazards and CCPs, it is important that the HACCP team is made up of people from a wide range of disciplines. There are a number of functions that the team must cover.

- There must be a chairman to convene the group and to direct the work of the team ensuring that the concept is properly applied. This person must be familiar with the technique, be a good listener and allow all participants to contribute.

- Someone with a detailed knowledge of the production processes (a production specialist) is required to draw up the initial flow diagrams.

- Several specialists may be involved in the team, each with an understanding of particular hazards and associated risks, for example, a microbiologist, a chemist, a quality control manager or a process engineer.

- People, such as packaging specialists, raw material buyers, distribution staff or production staff who are involved with the process, and have working knowledge of it, may be brought into the team temporarily to provide relevant expertise.

- The team's progress and results of the analysis should be recorded by a technical secretary.

If any changes are made to the composition or operational procedures, it may be necessary to alter the CCPs or change the methods of monitoring.

Stage 2 – Describe the product

A full description of the product should be prepared. This should include information relevant to safety information, for example, composition, physical/chemical structures of the raw materials and the final product, the amount of water available for microbial growth (*a*w), the amount of acid or alkali in the product (pH), and any treatments that will eliminate or reduce the level of micro-organisms such as heating, cooling, freezing, brining or smoking. Information on how the product is to be packaged, stored and transported should also be considered, together with facts regarding its shelf-life and recommended storage temperatures. Where appropriate, labelling information and an example of the label should be included. An example of a form that can be used by the team is shown in Figure 2.

Name of product	
Description	
Packaging	
Conditions of storage	
Shelf-life	
Instructions on the label	
Consumer group	
Recommendation further processing required before consumption	

Figure 2 Example of form – description and intended used of product.

Stage 3 – Identify the intended use of the products

How the product is intended to be used is an important consideration, i.e. is it to be cooked before eating? Consumers like to experiment with food so it is possible for food to be consumed raw, even when the manufacturer recommends cooking before consumption. All eventualities should be considered at this stage. Target groups in the population to whom the product may present a higher risk should be identified, for example, the young, elderly, immuno-compromised, or pregnant women.

Stage 4 – The process flow diagram

The first function of the team is to draw up a detailed flow diagram of the process. The expertise of the production specialist is important at this stage. Processes will differ in detail in different plants, and an accurate flow diagram depends on detailed knowledge of the process. An example of a process flow diagram (PFD) for Criol sausage is shown in Figure 3.

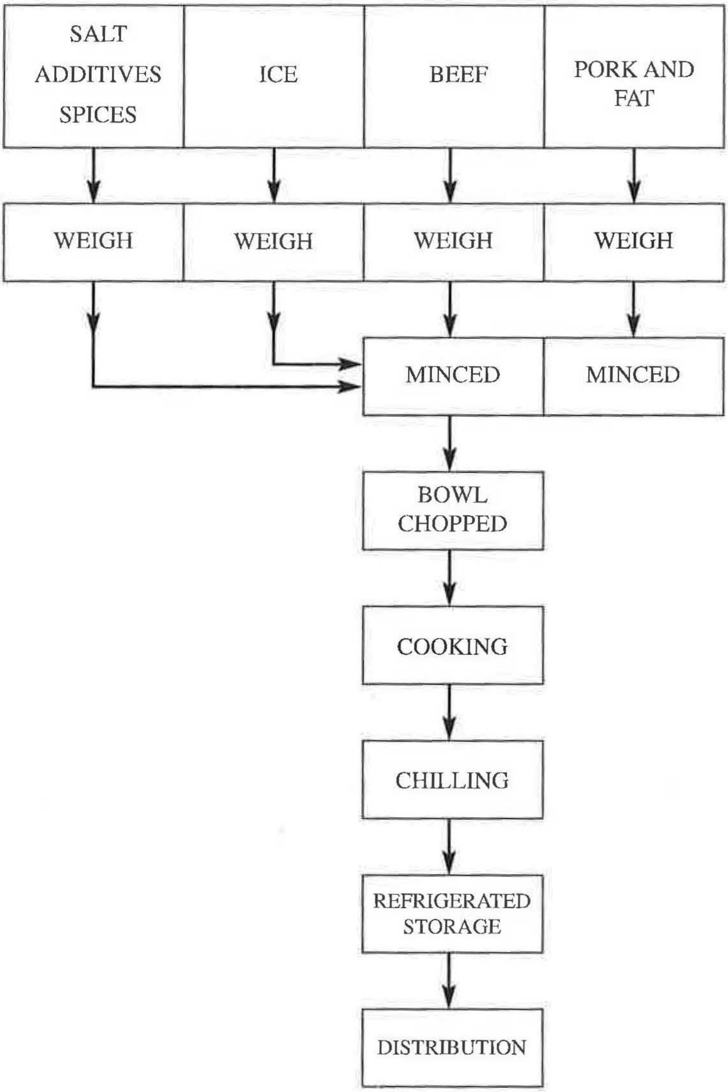


Figure 3 Process flow diagram.

Stage 5 – On-site verification of the PFD

Upon completion of the PFD, members of the team should visit the manufacturing area to compare the information on the PFD with what actually happens during production. This is known as 'walking the line', a step by step practice to check that all information regarding materials, equipment, controls, etc., has been taken into consideration by the team during the preparation of the PFD. Aspects such as time of production, deviations caused by different shift patterns, start-up, shut down, cleaning and especially night shifts should be monitored.

Stage 6 – Identify hazards and consider any measures required to control the identified hazards

Effective hazard identification and risk assessment are the keys to a successful HACCP. All real or potential hazards that may occur in each ingredient and at each stage of production should be considered. Potential hazards can be identified by the following means.

- Aetiological information, collected by public health laboratories, will provide data regarding factors known to have given rise to outbreaks of food-borne illness for particular products.

- Technical information collated on all aspects of production, raw material storage and handling, processing, storage, distribution and use of the product. This should include looking at the hygienic design of equipment and layout of the plant, hygiene and sanitation procedures in the plant, and the health and hygiene of personnel.

- Complaints records; shelf-life and challenge testing; modelling; libraries; consultancy.

Lists of some specific hazards that may be associated with a range of food products are given in Tables 1 and 2. The lists are by no means exhaustive and should be used only as a guide. There is also a list of bibliographic references at the end of this chapter. Microbiological hazards have been listed according to severity, i.e. will they make the consumer ill or are they life threatening? The severity of hazard is based on the stringency plan in relation to degree of health hazard and conditions for use presented by the ICMSF (1986). A similar approach can be used for other hazards.

Analysis of hazards is ideally both qualitative and quantitative as it needs to provide useful information on the potential severity of risks. The risk expresses the chance of a hazard occurring and the severity relates to the magnitude of the hazard. The resources allocated to controlling the hazard will be dependent on these factors. Control measures may control more than one hazard and more than one control measure may be required to control a single hazard.

Stage 7 – Determining CCPs

All ingredients and each stage of the process are taken in turn and the relevance of each identified hazard is considered. The team must determine whether the hazard can increase at this stage or whether it can be reduced, prevented or eliminated. If the hazard can be reduced, controlled, prevented or eliminated through exerting some form of control at a particular stage, it is a CCP. A decison tree can be used to determine CCPs, and an example of the Codex decision tree is shown in Figure 4. However, the judgement and expertise of the HACCP team are the major factors in establishing a CCP.

Table 1 Examples of microbiological hazards that may be associated with food and food products

Severe risk	Moderate risk Potential of extensive spread	Moderate risk Limited or no spread
Bacteria	**Bacteria**	**Bacteria**
Brucella melitensis (brucellosis) *Escherichia coli* O157:H7 *Clostridium botulinum* types A, B, E and F (botulism) *Clostridium perfringens* type C (Enteritis necriticans) *Shigella dysenteriae* 1 (shigellosis, dysentery) *Salmonella typhi* *Salmonella paratyphi* types A, B and C (typhoid and paratyphoid fevers) *Salmonella cholerae-suis* *Salmonella sendai* *Vibrio cholerae* 01 (cholera)	Pathogenic *Escherichia coli* ('traveller's diarrhoea') Other *Shigella* species (shigellosis) Other *Salmonella* species ß-haemolytic (salmonellosis) *Streptococcus* groups A, C and G (septic sore throat, scarlet fever)	*Bacillus cereus* *Campylobacter fetus* subsp. *jejuni* *Clostridium perfringens* type A *Listeria monocytogenes* (listeriosis) *Staphylococcus aureus* *Vibrio parahaemolyticus* *Yersinia enterocolitica* **Parasites** Amoeba Giardia
Virus		
Hepatitis A Poliovirus		
Toxins		
Algal toxins Mycotoxins		

Source: ICMSF (1986).

Table 2 Examples of chemical and physical risks that may be associated with food and food products

Chemical	Physical
Heavy metals Pesticide residues Lubricants/hydrocarbons from machinery Fumes/dust Refrigerants Pest control agents Chlorophenols Sanitizing agents Water additives Paints/printing inks/plasticizers	Natural extraneous material e.g. stalks, leaves, seed heads, bone, skin Foreign material e.g. insect infestation, stones, glass, animal droppings, metal, plastic, wood, paper, hair, jewellery, paint, plaster Others e.g. cross-packing, sabotage

Source: CCFRA (1992).

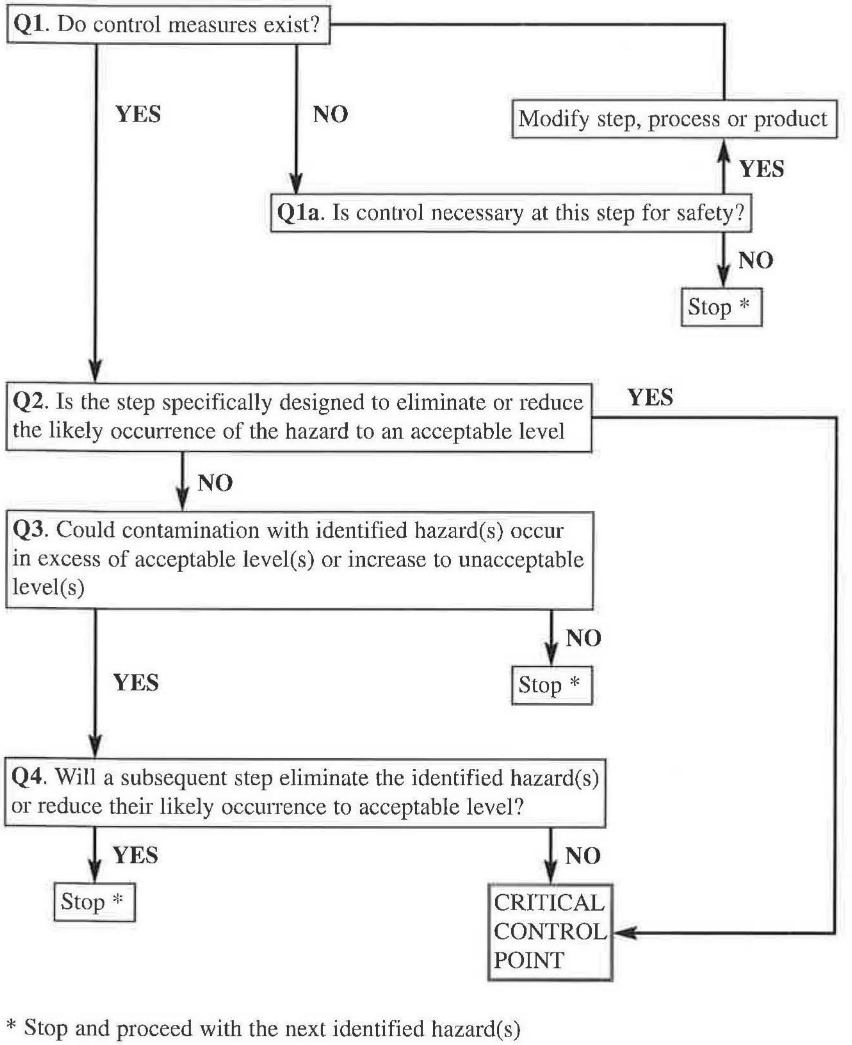


Figure 4 Decision tree.

It is important that all CCPs are controlled. When deciding on the extent to which the CCP will be monitored, a judgement of risk must be made so that a level of concern can be ascribed to it. There are four levels of concern:

- high concern – an expert judgement that without control there is a life threatening risk
- medium concern – an expert judgement that there is a threat to the consumer that must be controlled

- low concern – an expert judgement that there is little threat to the consumer; it may still be advantageous to control it
- no concern – an expert judgement that there is no threat to the consumer.

The points where control can be exerted, but are not critical because of low risk or severity, need less control and monitoring. If a hazard can be controlled at more than one point, the most effective place to control it must be determined.

Stage 8 – Critical limits

The team must next identify the means to control the hazard at each CCP. These may include, for example, chlorine levels in wash water, temperatures during storage, use of documented procedures. All must be documented as statements or included as specifications in operating manuals. Critical limits should be stated wherever appropriate.

Stage 9 – Monitoring procedures

Monitoring is the mechanism for confirming that processing or handling procedures at each CCP are under control. The method chosen for monitoring must be able to detect any loss of control, and to provide information early enough for corrective action to be taken and for loss of product to be avoided or minimized.

Monitoring can be carried out by observation or (although preferably continuous) by measurement on samples taken in accordance with a statistically based sampling plan. Monitoring by visual observation is basic but gives rapid results and can, therefore, be acted upon quickly. It is applicable to assessment of raw materials, worker hygiene, hygiene and sanitation procedures, and processing procedures. The most common measurements taken are time, temperature and pH. For raw materials, however, tests for toxins, additives, contaminants and microbiological tests may also be requested and the supplier may be required to use HACCP procedures.

Stage 10 – Corrective action

If monitoring indicates that criteria are not being met, or that the process is out of control, corrective action must be taken as soon as possible. The corrective action should take into account the worst case scenario, but must also be based on the assessment of hazards, risk and severity, and on the final use of the product.

The specific action will depend on the process. In a fruit and vegetable processing system, this may include re-washing fruit and vegetables, altering the chlorine concentration of water, or re-cleaning equipment. However, the traceability system must permit the quarentining of all potentially defective product made while the critical limit was being infringed.

Stage 11 – Verification

Once the HACCP plan has been drawn up it must be reviewed before being installed, and regularly reviewed once the system is operating. This might be a task of the person within the company with the responsibility for quality assurance (QA). The appropriateness of CCPs and control criteria can thus be determined, and the extent and effectiveness of monitoring can be verified. Microbiological tests can be used to confirm that the plan is in control and the product is meeting customer specifications. A formal internal auditing plan of the system will also demonstrate an ongoing commitment by the company to keeping the HACCP plan up to date, as well as representing an essential verification activity.

Ways in which the system can be verified include:

- collecting samples for analysis by a method different from the monitoring procedure
- asking questions of staff, especially CCP monitors
- observing operations at CCPs
- formal audit by an independent person.

It is important to remember that the HACCP system is set up for a particular formulation of product handled and processed in a given way.

Stage 12 – Documentation

Although not specifically required by law, record keeping is an essential part of the HACCP process. It demonstrates that the correct procedures have been followed from the start to the end of the process, offering product traceability. It provides a record of compliance with the limits set and can be used to identify problem areas. Furthermore, the documentation can be used by a company as evidence of ...'Due Diligence Defence'... required by the Food Safety Act 1990 (HMSO). An example of a control chart that can be used to summarize the HACCP plan is given in Figure 5.

There will be documents recording the actual HACCP study, for example, hazard identification and selection of critical limits, but the bulk of the documentation will be concerned with the monitoring of CCPs and corrective actions taken. Record keeping can be carried out in a number of ways, ranging from simple checklists, to records and control charts. Manual and computer records are equally appropriate, but most auditors prefer to work from paper records.

CCPs	RISK	CRITICAL LIMITS	MONITORING – WHAT	MONITORING – HOW	MONITORING – FREQUENCY	MONITORING – WHO	CORRECTIVE ACTIONS	RECORDS	VERIFICATION

Figure 5 Example of form – HACCP plan preparation.

CASE STUDIES

Recent approaches towards the control of the occurrence of food-borne diseases in developing countries are described below.

Appropriate quality systems for small- and medium-scale enterprises in Costa Rica

In Costa Rica, meat and meat products are distributed to a range of consumers through a variety of outlets including local markets, supermarkets and export markets. The last expect and demand quality attributes that will result in the rejection of the product, with concomitant economic losses to the livestock and meat industries, if the specified attributes are not met. Increasingly, as the quality consciousness of the local consumer increases, the internal markets are also likely to impose standards of quality that will mean rejection of meat produce that fails to meet the minimum standards. Opportunities for adding value will also be lost if the suppliers of meat and meat products do not adopt a more quality conscious attitude.

In collaboration with the Centro Nacional de Ciencia y Tecnologia de Alimentos (CITA), the introduction of appropriate quality systems for small- and medium-scale enterprises (SMEs) involved the following key components:

- a preliminary project workshop to promote the active participation of the key members of the meat industry
- training in good manufacturing practices (GMP), the HACCP system and quality management systems based on the BS EN ISO 9000 series was provided to key members of the meat industry
- the identification and surveillance of collaborating meat processors
- the design and implementation of appropriate quality systems
- follow-up surveillance of the collaborating meat processors to evaluate the efficacy of the new quality systems
- an end-of-project workshop to discuss and disseminate the project outputs.

The HACCP system

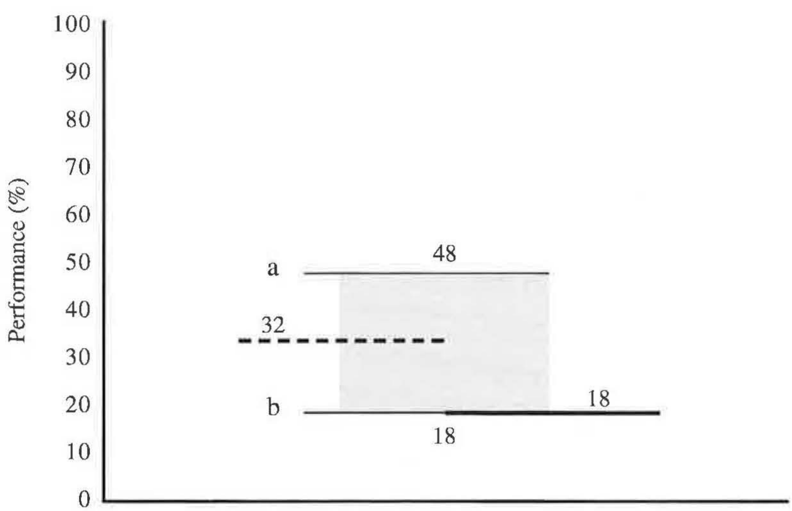
The HACCP concept is a preventative and systematic approach to hazard identification, assessment and control (see above). However, it is costly and inappropriate to attempt to transfer methods directly from developed to developing country meat industries and, to date, such attempts have met with little success. However, since HACCP is an approach and not a prescriptive system, the concept can be used to develop tailor-made systems applicable to the production and marketing of meat products in any country.

Such systems should incorporate control systems which combine both Manufacturing GMP and HACCP. GMP is a basic and subjective approach which addresses environmental conditions and the control of working procedures. However, when combined with the systematic approach used in the HACCP concept, its application results in a significant improvement in quality, and a reduction in related food-borne illness.

Training in HACCP and GMP was provided both in Costa Rica and in the UK, and included first-hand experience of how the British food industry follows and applies the legislative requirements of the European Union and USA.

Collaborating small- to medium-scale meat processors

Baseline surveys of seven representative SMEs were performed using a statistically based diagnostic approach developed by the CITA Quality Assurance Group. The handling and manufacturing protocols followed by each processor were evaluated using the following attributes: condition of the raw material, the process, the product, hygiene, equipment condition, and quality. Figure 6 illustrates the range of the overall performances for the attributes (expressed as a percentage), and the overall mean performance of the SMEs together with the overall performance of a single selected processor. It is evident that the



----- mean performance for SMEs
—— performance for selected SME
a maximum performance in group
b minimum performance in group

Figure 6 Performance of seven processors before the introduction of appropriate quality systems: overall performance quality.

performances varied from 18% to 48% with a mean value of 32%. The selected SME was associated with the lowest overall performance of 18%. The performance of the SMEs, in terms of the six individual attributes, is illustrated in Figure 7. For 'equipment', for example, the performance range varied from 20% to 50%, with a mean value of 38%, and the selected processor showed a performance of 20% for this attribute.

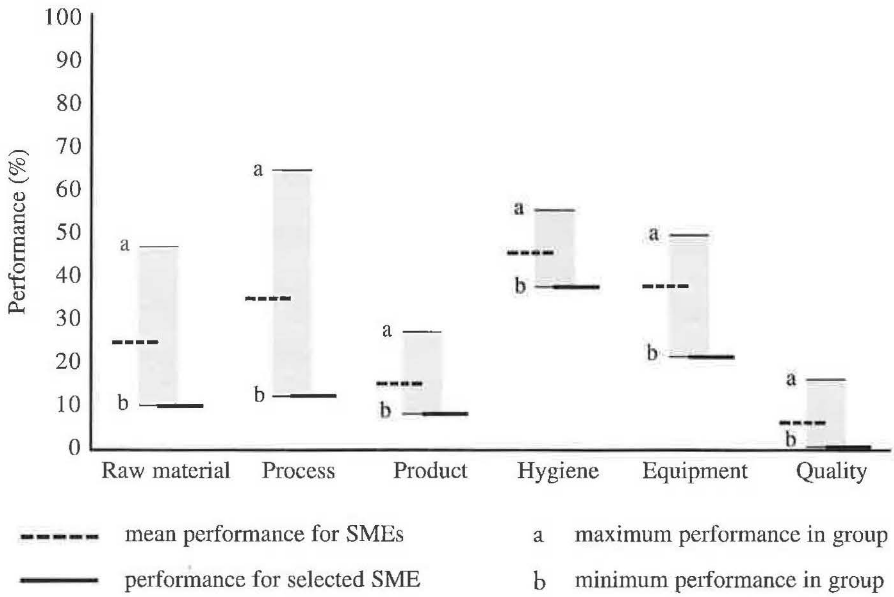


Figure 7 Performance of seven processors before the introduction of appropriate quality systems: quality of six processing and handling protocols.

Appropriate quality systems

After the baseline survey of the SMEs had been completed, flow diagrams describing the process used by each manufacturer were prepared and the CCPs identified.

A simplified process summary for salami, a popular meat product manufactured in Costa Rica is shown in Figure 8. Those constraints which were contributing to the non-enforcement of GMP (e.g. cost and lack of understanding) were also identified. An appropriate quality system was then designed and commissioned for each SME to improve the quality of the product.

Follow-up surveillance

After a 2-year period, the surveillance of the collaborating meat processors was repeated in order to evaluate the efficacy of the new quality systems. The results of the surveys showed a clear improvement in quality and are summarized in

PROCESS	MAIN DANGER POINTS	CORRECTIVE ACTION
Raw materials		
MINCED BEEF (0–5 °C)	Delays	Avoid delays Chill (0–5 °C)
CHOPPED PORK AND FAT (-50 °C)	Delays	Avoid delays Maintain in deep freeze (-20 °C)
DRY RAW MATERIALS	Incorrectly stored	Store all dry materials in a dry material store
Processing		
WEIGH INGREDIENTS	Incorrect weights Out of date ingredients	Calibrate scales Adequate training Operate stock rotation
PREPARE EMULSIONS	Delays Faulty machinery	Avoid delays Maintenance of equipment
STUFF INTO CASINGS	Poor filling Inadequate hygiene	Increased supervision Adequate training
COOKING (internal temperature 78 °C for 3 hours, RH–100%)	Incorrect times and temperatures	Check and monitor process Calibrated recording
COOLING 15 minutes to 40 °C	Contaminated water	Chlorinated chilling water
CHILLING to 5 °C	Delays Cross contamination	Avoid delays Good hygienic practices
STORAGE 0–5 °C	Incorrect storage	Temperature control Maintain records
DISTRIBUTION 3–5 °C	Poor temperature control during transportation	Specify the use of refrigerated trucks
RETAIL 3–5 °C	Inadequate temperature control Poor hygiene practices	Maintenance of equipment Adequate training

Figure 8 A simplified process flow diagram showing potential hazards for the production of salami.

Figures 9 and 10. The overall mean performance of the SMEs had increased from 32% to 46% (Figures 6 and 7), due to an increase in the performance associated with each of the six attributes (Figures 9 and 10). The selected SME demonstrated significant increases in performance over the 2-year period for each of the attributes, i.e. condition of raw material (20% increase), process (32%), product quality (15%), hygiene (10%), equipment (10%) and quality (15%).

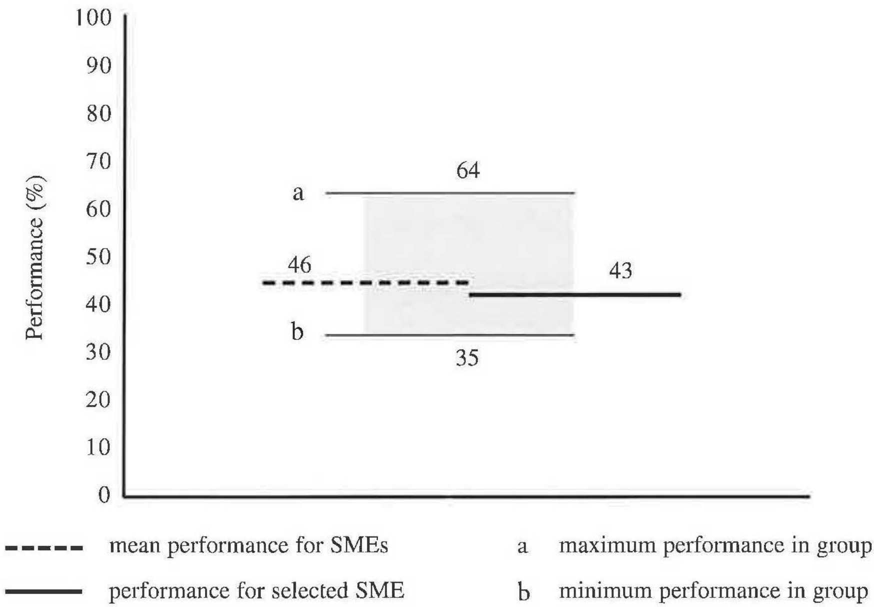


Figure 9 Performance of seven processors after the introduction of appropriate quality systems: overall performance quality.

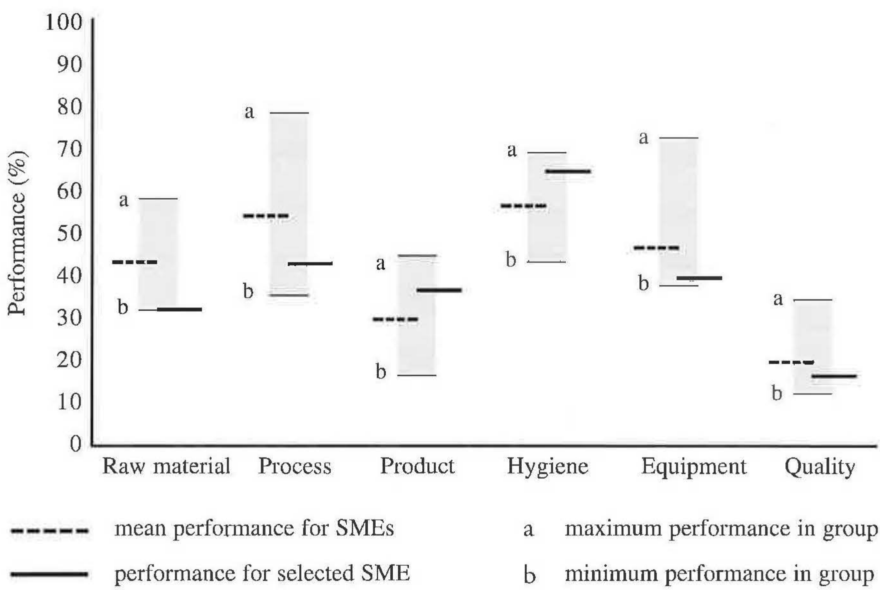


Figure 10 Performance of seven processors after the introduction of appropriate quality systems: quality of six processing and handling protocols.

End-of-project workshop

The experiences of the participating SMEs were reported and discussed at an end-of-project workshop which enabled the project outputs, including the benefits of the improved quality systems, to be disseminated to those members of the meat industry who had not directly participated in the project.

Training in the HACCP concept

DFID-funded programmes in Paraguay Instituto Nacional de Tecnologia y Normas (INTN), Ecuador Instituto Nacional de Pesca (INP) and India Central Institute for Fisheries Tecnologia (CIFT) have concentrated on capacitation of training of research institutions in the HACCP concept. A train-the-trainers approach was followed, whereby staff were trained in the principles and implementation of the HACCP concept. The teams then worked with local industries to implement the system into local food processing plants.

CONCLUSION

HACCP is a powerful and useful tool. Undertaking an HACCP study focuses the thinking of everyone involved on the details of the process, and promotes a greater awareness of safety issues. Implementation of an HACCP system is not an end in itself. It requires the commitment of management and the workforce, and constant monitoring of the system is needed to ensure its success.

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Chapter 8

REMOTE SENSING AND GIS DECISION SUPPORT TOOLS: APPLICATIONS FOR WILDLIFE AND RANGE MANAGEMENT IN TSETSE CONTROL AREAS

Ken Campbell

INTRODUCTION

Bovine trypanosomiasis transmitted by tsetse files has long been recognized as a constraint to livestock production over large parts of Africa (e.g. Maloo *et al.*, 1985; Ikomi and Ilemobade, 1983; Itty *et al.*, 1995). In areas affected by trypanosomiasis, tsetse control operations form an important component of rural development activities, whilst successful control is likely to act as a catalyst for a range of economic development activities. In general, control is undertaken to facilitate human settlement and modification of the agricultural base through improvements in livestock-based production systems. In the past this control has taken a variety of forms, from the wholescale removal of woody vegetation in order to remove tsetse habitat, for example, in Tanzania (Mugasha and Nshubemuki, 1988; Otsyina *et al.*, 1996), through to the extensive wildlife culling operations to remove host species, for example, in Zimbabwe. Whilst such destructive control techniques are no longer practised, the long-term impacts of such clearance operations are still felt. It is fair to say that many of those impacts were unforeseen when control operations were initiated. More recent tsetse control techniques include chemical spraying (Groome *et al.*, 1984) and, increasingly, the use of traps (Allsopp *et al.*, 1985; Wall and Langley, 1991; Warnes, 1991) or integrated techniques (Kangwagye *et al.*, 1988; Marchot *et al.*, 1991). Whilst operational control measures are increasingly sophisticated (Allsopp, 1992, 1994), there is a growing awareness amongst both the international donor community and national land use managers of the need to monitor the impacts of tsetse control operations and subsequent rural development, from both environmental and socio-economic perspectives.

NATURE OF THE PROBLEM

The introduction or development of livestock is not only dependent on tsetse control, but on a wide range of environmental, social and economic factors. However, the removal of tsetse is seen by many as an important precondition for many forms of livestock development and, in practice, tends to lead to increases in cattle numbers, to the availability of draught animal power and to changes in the composition and structure of herds (Pender and Rosenberg, 1995). Changes such as these are also likely to result in, and accompany modified patterns of rural migration, local increases in human settlement, and significant changes in demand for renewable natural resources. Whilst tsetse control is considered to be a component of rural development, removal of tsetse has also been viewed as a threat to protected areas. The possibility that control and eventual removal of tsetse from an area may result in environmental degradation due to unplanned increases and expansion in livestock and settlement has meant that tsetse control remains a contentious issue (Barrett *et al.*, 1989; Jordan, 1992) but there can be little doubt that sub-optimal land use has occurred in tsetse-freed areas (WWF, 1987). Tsetse control operations themselves may also have an impact on the environment, and ultimately on man, as a result of the build-up of chemical residues (Douthwaite and Tingle, 1994).

A recognition that tsetse control is only one aspect of rural development is important (Pender and Rosenberg, 1995). There is a growing awareness that such programmes require the support of a wide variety of socio-economic and environmental information and an assessment of land use potential if they are to lead to rural development as opposed to land degradation, with Barrett (1989) and others suggesting the necessity for stronger links between tsetse control policy and rural development. There is also increasing evidence supporting the view that eradication of tsetse fly may contribute to ecological degradation, which, when sufficiently advanced, can induce an increase in aridity (Ormerod, 1986) with implications for climate change. With new advances in technology it is now possible for such populations to be 'managed' in order to protect vulnerable rangelands (Ormerod *et al.*, 1990). Such a concept necessitates changes in attitudes towards tsetse, with society needing to regard them as a potential asset rather than purely as a liability.

Areas suitable for tsetse are largely grazing and semi-arid land systems. These lands are generally characterized by a slow response to management, either good or bad (Conner, 1993). For this reason, it is difficult to distinguish between temporary responses of grazing lands in response to normal climatic fluctuation and longer term, fundamental ecological changes that result from land management practices. Much grazing land has been subjected to a gradual modification, deterioration or degradation over the years. Changes are slow, in some cases occurring over several generations. They may be masked by seasonal fluctuations and are seldom perceived by resource managers as having resulted from their actions. Tsetse control in such areas has in the past resulted in land degradation, as can be illustrated by examples.

Large-scale soil conservation programmes are now required in a semi-arid area of Tanzania which had been repeatedly cleared of vegetation (especially the *Brachystegia* woodland communities) for the control of tsetse (Mugasha and Nshubemuki, 1988). In addition to land degradation, people in Shinyanga region of Tanzania, now find themselves chronically short of both fuelwood and fodder as a result of massive deforestation campaigns that were intended to eliminate tsetse (Otsyina *et al.*, 1996). As a result, there have been large-scale movements of livestock away from Shinyanga region to other parts of Tanzania (Figure 1), many moving to the periphery of national parks, game reserves and other areas where grazing resources are less scarce (Meertens *et al.*, 1995). However, much of this new land is also occupied by tsetse and, although tsetse control is not the only factor involved, one, nevertheless, has the somewhat curious situation where an original tsetse eradication programme has eventually resulted in large-scale movement of livestock back into tsetse areas.

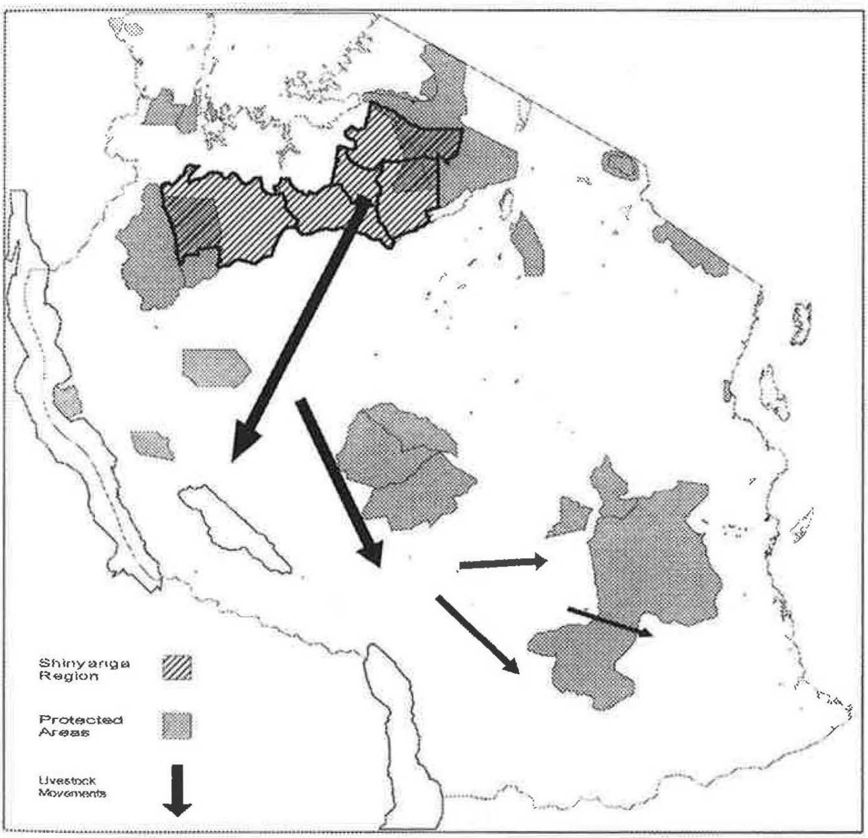

Figure 1 Diagrammatic representation of livestock movements away from Shinyanga Region, Tanzania.

All strategies intended to meet the needs of increased food demands should, as a matter of policy, consider the potential impact of agricultural and other interventions on the environment. Projects that involve the use of pesticides, the control or eradication of animal diseases and consequent changes in land use, are particularly subject to conflicting pressures from political constituencies, environmental and conservation lobbies. Tsetse and trypanosomiasis control represent particularly contentious interventions in both semi-arid and humid forest zones. In order to assess the environmental and socio-economic impacts of tsetse control operations, over both short-term and longer time-scales, and to provide the supporting information required during control programmes, a long-term programme of environmental and socio-economic inventory and monitoring closely linked to land use planning, is clearly needed. Of course, this is not limited only to tsetse control but is an important and a necessary central component of a majority of development programmes. As such, this chapter views problems related to decision support in tsetse control areas as generic problems that can be solved by the application and integration of generic tools, perhaps derived from a range of different disciplines. Essentially the problem is one of holistic data management whereby environmental and socio-economic data are analysed and integrated to produce information relevant to the problem in hand, in a format that is suitable for, and can be used by, national and local resource managers. The role of simulation and modelling is also important (e.g. Milligan *et al.*, 1990; Williams, 1995) since these techniques are capable, when used with due caution, of providing potentially valuable information as an aid to decision-making. It is at this point that the need for decision support systems (DSS) becomes apparent. The multidimensional, dynamic relationships between the ecosystem, where production is dependent on renewable resources, and the need to account for goal attainment, are too complex for resource managers to integrate into decision processes without considerable assistance (Conner, 1993). DSS enable resource managers to obtain answers to 'what if' questions in a way that would otherwise be impossible or impractical to answer. What roles can remote sensing and geographical information systems (GIS) play in supporting the DSS?

REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEMS AS DECISION SUPPORT TOOLS

Both remote sensing and GIS have potentially important roles to play in the development of natural resources (NR) decision support systems. Remote sensing is simply "observation of objects and features without touching them" (Perryman, 1996). Important observation platforms utilized by remote sensing include satellites and aircraft (Table 1). GIS provides the means for storing and analysing large, spatially referenced data sets (Perry *et al.*, 1994). Remote sensing techniques, whether from satellite or aircraft, form a mechanism for obtaining significant parts of that data in the first place (e.g. De Wispelaere and Wispelaere, 1994; Campbell and Hofer, 1995).

Table 1 Overview of sources of remotely sensed data and typical usage

Platform	Data source	Typical usage	Frequency	Resolution
Low resolution satellite remote sensing	Meteosat	Climate monitoring, especially rainfall, ground temperature	half hour	5–7 km
	NOAA-AVHRR	Vegetation dynamics Fire monitoring Drought assessment Yield estimation	12 hours	1.1 km (or greater in some processed products)
High resolution satellite remote sensing	Landsat, SPOT, IRS and others	Habitat type, Land cover classification	16–20 days	10–30 m
Low level aerial survey	Observer data typically sampled	Livestock numbers Wildlife numbers Human settlement	User defined typically seasonal	Individual animal
	Sample photographic data either digital or conventional	Land use description Quantification of land use and land cover parameters Human settlement Frequent monitoring at high resolution	User defined typically seasonal	Less than 10 cm to 1 m level

Collection of data over large areas by ground-based techniques can be both time consuming and costly. In many cases it is either impossible or impractical to obtain a comprehensive coverage through ground sampling within time-frames that are relevant to the observations and in such a way that the information can be used as a basis for informed decisions. Remote sensing plays an important role in extending and interpolating limited ground-derived data sets to whole regions. Questions of scale and resolution are fundamental and govern much of the information content of remotely sensed data. A system's capabilities can be summarized in terms of spatial, temporal, spectral and radiometric resolution and the following definitions (Perryman, 1996) serve to illustrate these four concepts:

- spatial resolution represents the size of the smallest unit of the image that can be seen; it provides a lower limit to size of the smallest object discernible by the system

- the temporal resolution of a sensor is the shortest possible reliable return period and governs how often observations can be made
- spectral resolution is determined by the number of bands, or parts of the spectrum, recorded by the sensor and the properties, or widths, of the individual bands
- radiometric resolution is the number of different levels of brightness possible within each band.

Recent developments in imaging technology, coupled with cost-effective global positioning systems (GPS), allow aerial survey count data and digital aerial photography to be geo-referenced and imported directly into a DSS at the scale of individual land holdings, providing information at a high spatial resolution. At the other end of the scale, Eumetsat's Meteosat satellite transmits half-hourly images largely consisting of weather-related information covering the whole of Africa at a relatively low spatial resolution (5 km at latitude 0 and longitude 0), but high temporal resolution (Table 1). NOAA satellites pass overhead daily transmitting 1 km resolution data useful over national and regional scales for a wide variety of applications including near-real-time fire monitoring (Flasse and Ceccato, 1996), examination of vegetation dynamics, drought monitoring, crop yield forecasting (Sannier *et al.*, 1996, 1997) and for prediction of distribution and abundance of tsetse (Rogers *et al.*, 1996). The high temporal resolution of NOAA satellite systems, coupled with a time-series of data over the last 10 or 15 years enables dynamic environmental processes to be viewed within a (limited) historical perspective. In between these extremes lie the high resolution satellites, Landsat, SPOT, IRS and others recording data that can be processed to present relatively detailed information on land cover over large areas.

Low level aerial survey

Non-satellite sources of remotely sensed data that may be particularly useful in tsetse control areas include low level aerial survey techniques and aerial photography from the same light aircraft platforms. Conventional, large-format aerial photography has long been used as a primary data source in the production of topographic maps. However, if aerial photography is not already available, survey missions are costly and the technique is rarely available as a tool for use by individual studies. Nevertheless, irregular historical time-series of aerial photography exist for some areas and provide a valuable source of information on land use and changes in land use (Pender and Rosenberg, 1995). On the other hand, low level aerial survey techniques are relatively easy to implement, can sample large areas in a short time, and are able to produce data on land use, the numbers of livestock or wildlife and in many cases, the density of human settlement (Norton-Griffiths, 1988).

In the early 1960s light aircraft began to be widely used in Africa and North America, especially by wildlife biologists faced with the task of studying large populations of animals in extensive and often undeveloped areas. In many areas roads were poor, cross-country travel difficult, and suitable maps non-existent. Light aircraft provided a highly mobile observation platform. This rudimentary beginning led to a number of observation and survey methods that are now widely used in many parts of the world.

The available data recording methods need to be seen within the overall framework of techniques suited for use with light aircraft. These methods share a number of common characteristics. Firstly, they are sampling methods, meaning that only a small portion of the total study area is examined, but that portion can be examined in some considerable detail. Secondly, the aircraft used are high-wing, usually single-engined aircraft that provide observers with an unobstructed view of the ground. Thirdly, data can be collected both by direct observation and by photography. Finally, the aircraft are flown at slow speed and relatively close to the ground. Observers are able to record and estimate a wide range of parameters. The use of light aircraft for monitoring wildlife and livestock numbers is also closely related to photographic methods. In many cases a combined approach can be adopted where data are simultaneously collected by observers (estimates of animal numbers) and by photographic means (typically collecting land cover and habitat level information).

Systematic reconnaissance flight

For broad-scale regional surveys, and for monitoring of a wide range of attributes, a sampling strategy termed the systematic reconnaissance flight (SRF) allows large areas of country to be covered on a routine basis. This method has been applied for both inventory and monitoring purposes in areas ranging from 50 to 500 000 km^2, as well as over entire countries. SRF was developed initially to study the seasonal movements of domestic stock and wildlife, and the seasonal patterns of associated environmental factors, such as grazing resources, water and fire. More recently, the SRF has evolved into a cost-effective method for rapid survey, inventory and monitoring of renewable natural resources over very large areas, whilst environmental factors, such as fire and grazing resources, can now be quantified by alternative techniques (especially using low-resolution satellite imagery). Typically, SRFs are now used to quantify the abundance and seasonal distribution of domestic stock and wildlife, and to quantify patterns of settlement, land use and agricultural activities.

SRF is a sampling technique for quantifying the spatial distribution of land use parameters through a combination of visual observations and vertical photography from low-flying, high-wing light aircraft. The aircraft flies parallel flight lines (transects) across the study area at a ground speed of about 180 kph and at heights between 90 and 120 m above ground level. Visual observations are recorded continuously along the length of each transect, but are divided into successive 'sub-units' on the bias of elapsed time (e.g. 30 seconds) or distance (such as 5 km). One or more vertical sample photographs are taken within each sub-unit, and all data recorded during the survey are cross-referenced to individual transects and sub-units.

Although the spacing of transects can be varied depending on survey area and objectives, it is the navigation of the aircraft along these flight lines which is of fundamental importance. Use of satellite-based GPS as a navigation aid has greatly improved the potential for accurate geo-referencing of recorded observations, facilitating incorporation of aerial survey data into GIS. A key characteristic of the SRF method is that it delivers a set of data points, each of which can be geo-referenced to a high degree of accuracy.

The width of the observers sampling strip and the area recorded through vertical photography both depend on the height of the aircraft above ground level. This is controlled by reference to a radar altimeter, with readings being recorded at least once for every sub-unit.

The SRF is typically carried out within the framework of a sampling grid, and the Universal Transverse Mercator (UTM) system is widely used as a sampling frame. The UTM system is an international co-ordinate system originally developed by the US Army, now projected on to many topographic maps world-wide and available within computerized cartographic or GIS software. Each sub-unit can be assigned to individual grid cells, and each grid cell contains a unique set of sub-units. Grid cells have important uses. They provide standard locational information and convenient thematic mapping units. They can also be used to standardize map and thematic information and for the incorporation of ancillary data. There are close relationships between systems for analysing grid-based aerial survey data and GIS and image analysis techniques.

The SRF method is particularly appropriate under the following conditions (Clarke, 1986):

- for multidisciplinary development programmes in large study areas, where each facet of the programme is involved with different aspects of the environment and development potential

- when it is important to quantify the seasonal distributions and abundance of resources, and the seasonal distributions of land use patterns

- when a wide range of ancillary data is to be incorporated into the data set

- when it is important to analyse the influence of environmental variation, land tenure and land use policy, infrastructure and service networks, on the distribution, abundance and utilization of resources, and land use patterns.

A wide range of practical and logistical considerations need to be taken into account during aerial surveys, including the nature of survey crew duties, the training or experience required, and methods for data standardization, validation, recording and analysis. To apply these methods successfully calls for a high degree of skill, training and dedication from those involved. Although the methods appear seductively simple to carry out, erroneous and misleading data will be collected if methods are misapplied, leading to a waste of financial and human resources, as well as the risk of inappropriate management decisions.

Such considerations are not limited to the conduct of aerial surveys. For example, inappropriate or incorrectly applied techniques for geo-correcting satellite images can result in errors of several kilometres and when combined with ground survey data (itself subject to positioning errors) considerable confusion and error can occur in the resulting land cover or land use analysis.

Observer counts of wildlife and livestock

Visual observations of livestock and/or wildlife are made by observers sitting in the rear seats of the aircraft. They continuously scan a strip of about 150 m (or more in some areas) that is typically demarcated by sets of parallel rods attached to the wing struts of the aircraft (Norton-Griffiths, 1978). Observers record data on to tape for later transcription, along with time-related information to distinguish between successive sub-units. Domestic stock and wildlife can be totalled for each sub-unit. Large herds can also be photographed for more accurate counting at a later date. An example of output from an aerial survey carried out in western Tanzania is shown in Figure 2.

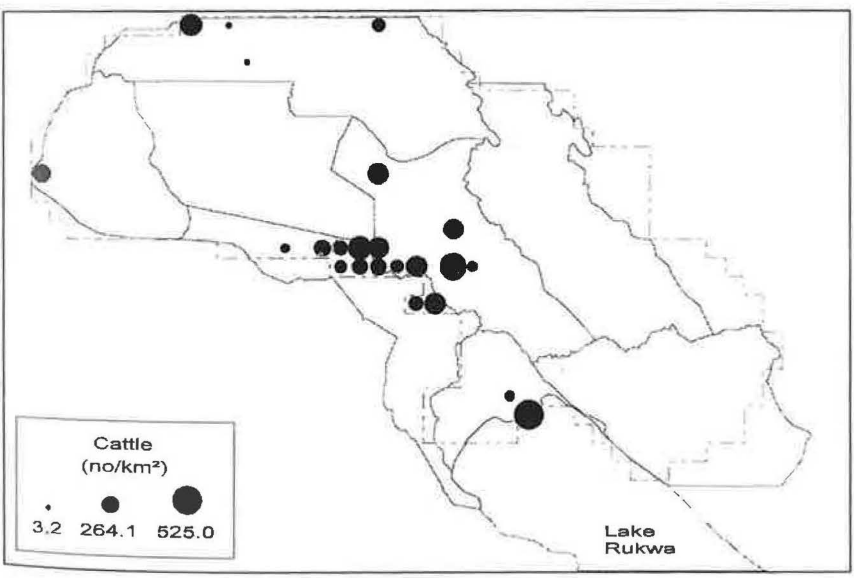

Figure 2 Example of results from a low-level aerial survey in the Lake Rukwa area, western Tanzania, 1991. *Source*: Campbell and Huish (1992). Graduated symbols represent observed cattle density in 5 x 5 km grid squares. Dashed lines represent the limits of the survey area.

Aerial survey data represent an important source of information on both the distribution and the population sizes of both wildlife and livestock. Data can be represented either as points or as polygons and can be directly related to other data sources (ground survey, cattle-crush figures, marketing data, etc.). The systematic sampling technique employed ensures an absence of the spatial biases inherent in ground sampling and censusing techniques. Compared with a majority of ground-based data sources, the accuracy of geo-referenced aerial survey data, the generally smaller sampling units (sub-units along each transect), and the comprehensive and systematic sampling effort result in a data set that can be combined and correlated with a wide variety of other information. The more rugged and inaccessible the terrain, and the larger the census zone, the more precise and efficient aerial surveys are found to be, when compared with alternative means of obtaining the same information.

In Tanzania, a long-term wildlife monitoring programme made extensive use of aerial survey methods to provide information on population numbers, distribution and also evidence of illegal tree felling and poaching activities (McNaughton and Campbell, 1991; Campbell and Borner, 1995). Although these surveys were not specifically targeted at livestock enumeration, livestock were counted when encountered, sometimes in large numbers. In Botswana, the Department of Wildlife and National Parks regularly census both wildlife and livestock and this has recently been carried out on a national scale at least once each year. These data form an important source of information on both wildlife and livestock numbers and distribution and are of particular importance in that data are not biased by accessibility in the same way that ground-based surveys are. As a result, distribution data are likely to be more reliable. In addition, the relatively short sampling time-frame means that it is considerably easier to correlate aerial survey data with sources of environmental information, such as satellite-derived vegetation greenness.

Using information from aerial surveys, Wint and Bourn (1994) found strong quantitative links between levels of erosion and the human activities likely to degrade environments (cultivation and livestock production), particularly in dry areas with relatively little vegetation cover. Findings such as these have implications for development policies and also indicate the considerable potential of aerial survey data as a component of DSS.

Aerial photographic sampling

Light aircraft have been used very effectively for monitoring vegetation changes, and have provided a cost-effective alternative to large-format aerial photography. Techniques have been based most commonly on the use of 35-mm cameras combined with motor-driven bulk film backs using colour transparency film. These are relatively easily mounted in a light aircraft, using a camera hatch or alternative custom-made mounts.

Vertical 35-mm colour sample diapositives taken along the length of each transect provide a source of data on vegetation and land use characteristics. A vertically mounted 35-mm camera, fitted with wide angle lens (typically 18 mm) photographs an area of approximately 4 ha at a flying height of 120 m, an image scale of 1:6700. The actual flying height is recorded each time a photograph is taken, enabling the photo-scale to be calculated for each frame individually.

The photographs provide two types of data: count and area. Count data are enumerations of objects on the colour slides such as buildings, cattle dips, individual trees, or animal tracks and erosion gullies. Area data include measurements of the proportional area on the sample colour slides of different land-cover classes. Area data can be obtained for cover types such as: land under active cultivation, land under different crops and inter-crops, fields of different sizes, land taken up by roads and tracks, house compounds, fallow land, land under different vegetation classifications, canopy cover of tree, bush and herbaceous components of the natural vegetation, area of bare ground, and area covered by sheet or gully erosion.

Nikon cameras are fitted with motor drives and 250 exposure backs of which 220 frames can be considered as usable. The choice of lens depends on the flying height and the required scale of photography. For photography combined with animal counts an 18-mm lens is recommended as this maximizes the photo area at low flying heights. Photographs can be projected on to white surfaces at 10 times enlargement for interpretation at scales of about 1:700. Construction of the necessary ports in the skin of the aircraft is relatively simple and no special mounts are required since high shutter speeds can be used. Cameras can also be mounted outside on brackets attached to the rear luggage compartment door (usually replacing the door). A recommended system consists of two cameras, with control cords running to the front seat of the aircraft. These can be fired simply by a push-button, although electronic timers can also be used. A dual camera system has many advantages. First, a second camera is available as a back-up in case one fails. Secondly, a total of 440 frames are available and this permits a significant area of country to be sampled in a single flight before reloading is required. In general, reloading in the air is difficult, liable to result in problems, and is not recommended. Thirdly, the two cameras can be fitted with lenses of different focal lengths, for example, 18 mm and 50 mm. When fired simultaneously, a large-scale sample at the centre of a small-scale photograph covering a much larger area of country is provided and different types of information can be recorded from each. Several examples serve to illustrate the use of these techniques.

In Kenya, a number of long-term vegetation studies have been implemented in the arid rangelands of Turkana District, Kenya (Clarke, 1986). On the upper Turkwell river, 35-mm sample photography from light aircraft was obtained along an 80-km stretch covering ten irrigation schemes. These attracted a large number of destitute Turkana over and above those formerly settled on them. Informal settlements and agriculture sprung up, both people and agriculture competing with tenant farmers for infrastructure and services. The same area also provided important dry-season grazing and watering resources for nomadic Turkana. The 35-mm sample photography had a number of objectives, including mapping settlements and counting structures within them, measuring areas of informal and irrigated cultivation, and measuring the impact of these settlements on resources such as woody canopy. Elsewhere in Turkana District, routine 35-mm sample photography was used to monitor environmental impacts of famine relief camps and development schemes, specifically on important riverine resources. Long-term vegetation dynamics are also being studied, specifically to study the process of desertification.

In Tanzania, 35-mm sample photographs taken from a flying height of 120 m were used to record and monitor a range of land cover and vegetation parameters over some 30 000 km^2 of the Serengeti ecosystem (Campbell and Hofer, 1995; Hofer *et al.*, 1996). Parameters measured included: tree and bush woody canopy cover and type, grass cover and type, extent of bare ground, rocky ground, numbers of dead trees, as well as numbers of structures such as settlements and livestock compounds. Each sample photograph covered between 4 and 8 ha, depending on actual flying height. Radar altimeter readings recorded at the same time as the photographs enabled an accurate assessment of photo scale and sample area. These data were obtained simultaneously with observer estimates of animal numbers, greatly enhancing the utility of both data sets.

In another survey, sample photographs taken from 460 m above ground level and, therefore, covering a greater area than in the previous example, enabled the determination of major habitat types and land cover parameters (Campbell, 1987). At such flying heights simultaneous enumeration by observers of small features or objects (e.g. wildlife or livestock) on the ground is not feasible but important land use categories, such as cultivated area, woody vegetation or percentage grassland, can be easily determined. Comparison of estimates from different sources, and repeated measures of vegetation categories over time indicate a high degree of accuracy and repeatability (Wint and Bourn, 1994).

The Office of Arid Lands Studies at the University of Arizona has been extremely active in developing the application of 35-mm sample photography for monitoring arid rangelands (Clarke, 1986; Knapp *et al.*, 1990). This has primarily centred on the long-term monitoring of control plots which are also visited on the ground. Ground-truth data are then used to interpret more extensive photographic sampling.

Aerial digital photography

Recent advances in digital photography have resulted in digital camera systems capable of rivalling the resolution of conventional 35-mm camera systems. Systems developed by Kodak are available for use as camera backs attached to Nikon camera systems (Koh *et al.*, 1996). These camera backs rely on the use of a charge coupled device (CCD) to record the scene instead of film, and two types of digital camera system can be distinguished, panchromatic and multi-spectral. Panchromatic systems were available first and have been adapted for use in recording a range of NR parameters. More recently a colour system has been made available. Although, complete coverage can be achieved with some difficulty, digital cameras are best considered as a sampling tool. With careful sample design aerial digital photography can be combined with both detailed ground survey work and satellite remote sensing techniques.

An important advantage is that the images can be viewed within minutes of landing, instead of waiting for film development, and that digital image processing techniques can be utilized. Data are recorded in a 'what-you-see-is what-you-get' fashion and a higher success rate of aerial survey missions can be expected. In contrast to standard colour film, these digital cameras record a wider range of wavelengths, including part of the infra-red spectrum, and with suitable filters facilitate a comparison with satellite imagery. Disadvantages include a reduced field of view meaning that effective sample area is reduced when compared with conventional camera systems.

The potential for aerial census in tsetse control areas

Light aircraft are regularly used for large mammal censuses in wildlife areas throughout southern Africa. These game counts include elephant, buffalo and a wide range of antelope species and the techniques are well understood. Aerial inspections and censuses could also be a rapid, practical and inexpensive means of undertaking livestock counts. Regular seasonal or annual livestock counts can provide up-to-date information on livestock distribution and numbers (more rapidly and with greater consistency than alternative methods) and can indicate whether livestock are being moved into proscribed areas. At the same time, new households or settlement can be identified, and observations made on factors such as indiscriminate tree felling. Combined with vertical aerial 35-mm sample photography, additional information can be made available on the distribution and areas of different crop types, and such factors as the prevalence or severity of soil erosion. Except within relatively small areas, aerial census is probably the only practical means of conducting game counts, and will, therefore, need to be catered for in monitoring programmes in tsetse control areas where wildlife management is a feature of land use plans. The expansion of the technique to cover regular collection of additional information on livestock, settlement and agriculture would be of significant benefit.

Satellite remote sensing

Satellite remote sensing data are increasingly used as components of DSS. In the UK, remote sensing forms an important component of the NERC-ESRC Land Use Programme (Wadsworth, 1996) whilst in the US, satellite data are extensively used in land use programmes, for example, the Gap analysis programme (Davis *et al.*, 1990; Jennings, 1993). However, satellite remote sensing is not limited to 'first world', high technology applications and has an increasingly important role to play in developing countries (Haines, 1996). In particular, the NRI, Department for International Development (DFID)-funded LARST (Local Application of Remote Sensing Techniques) programme has pioneered the use of direct reception of satellite data on personal computers (Williams and Rosenberg, 1993; Perryman, 1996). These techniques have been developed as practical and cost-effective tools to assist many different aspects of resource management and to monitor changes in the environment, with emphasis being placed on empowering local managers *in time to respond.*

Satellite imagery provides general overviews of regions or entire countries, can be used in areas where few or no ground data exist, can provide a basis for repetitive inventorying and for monitoring transient environmental changes on the earth's surface, and can aid in solving special problems of disease-vector control or human activity. Satellite remote sensing clearly has an important role to play in the inventory of habitats and land use and, through repeated measurement, in monitoring changes in these parameters within and adjacent to tsetse control areas. Pender and Rosenberg (1995) used a combination of historical aerial photography and Landsat TM imagery along with ground data to characterize land cover over some 8500 km^2 of tsetse control area south of Lake Kariba. The incorporation of these data in a GIS established a baseline on which further analysis and monitoring work and an environmental impact assessment of tsetse control was based (Mills and Pender, 1996).

In another study, potential tsetse habitats were characterized and identified through the use of remotely sensed imagery (Rogers, 1991; Rogers *et al.*, 1994; Rogers *et al.*, 1996) through analysis of time-series of normalized difference vegetation index (NDVI) and tsetse distribution. Rogers (1991) and Brady *et al.* (1991) also note correlation of both vector mortality and physical size of the flies with NDVI, whilst Hay *et al.* (1996) provide an overview of how satellite meteorological data may be used in studies of the population dynamics of arthropod disease vectors. The usefulness of satellite imagery in multivariate analysis of vector distribution was further explored by Rogers and Randolph (1993) and by Rogers *et al.* (1993). In these examples GIS also plays a vital role in integrating different data sources. These examples differentiate between, on the one hand, the use of high spatial resolution, low temporal resolution imagery for detailed land cover analysis, and on the other, the utilization of time-series of low spatial resolution but high temporal resolution satellite data for characterizing land surface by its dynamic response to environmental stimuli. The former represents perhaps a classic approach towards the use of remotely sensed imagery, is well served by standard image processing software, is relatively well understood and forms components of university degree courses. In tsetse control areas, these techniques can be combined with ground-based data and used to create a detailed inventory describing current or baseline conditions that form the basis for a DSS. However, it is the latter approach, largely the use of low-cost (or free), low spatial resolution imagery from meteorological satellites, that perhaps has the most to contribute directly towards the operational management of tsetse control areas. Applications of NOAA satellite imagery with particular application to tsetse control areas include fire detection and the characterization of vegetation dynamics, including famine early warning.

Fire detection

Although fire can be both a useful and efficient tool in environmental management, its misuse can have adverse results. Areas of concern include the sustainability of renewable natural resources, conservation of biodiversity, the destruction of valuable commercial timber and threats to settlements. In tsetse control areas in particular, fire is likely to be commonly used to solve problems ranging from land clearance or field preparation, to the control of ticks and the promotion of a green flush, whilst also being used in honey collection. Control of fire is difficult and in many cases excessive destruction is inevitable. As a result there are increasing pressures for improved fire management. Whilst a comprehensive analysis of fire data can improve understanding and facilitate better management decisions, much of the necessary monitoring information is normally absent.

The most practical, feasible and cost-effective means to quantify and monitor fires involves the use of remote sensing and GIS technology. In order to be of use to management on local and national scales, fire monitoring information needs to be received locally. NRI's LARST initiative (Williams and Rosenberg, 1993) enables the direct reception of NOAA advanced very high resolution radiometer (AVHRR) data and the operational production of fire products in a format that can be assimilated by managers at national and local scales (Flasse and Ceccato, 1996; Flasse *et al.*, 1997). This source of information is ideally suited to tackling the problems posed by fire in tsetse control areas, especially where baited traps form a component of a control programme. Fire can represent a significant hazard with serious impacts on control operations themselves, for example, the destruction of tsetse traps and targets by fire. At another level, fire is capable of destroying large quantities of graze and browse that would otherwise be available for livestock. In both cases protection against fire has obvious advantages. A detailed knowledge of fire occurrence enables better and more timely decisions. With a knowledge of burnt areas, limited time and resources can be better targeted towards checking and replacing damaged trap sites (G. Slade, personal communication; R. Allsopp, personal communication). The use of modelling techniques incorporating ground-based and remotely sensed data and GIS, enables the development of a means of fire risk assessment. The development of fire risk assessment in Etosha National Park, Namibia, was based on the model shown in Figure 3 and such techniques can be adapted relatively easily for use elsewhere.

Ground surveys

Remotely sensed data cannot be used on their own but must be combined with, in some cases, quite extensive ground data collection exercises. Whilst this chapter does not intend to discuss the collection of ground-based information for tsetse-related studies, it nevertheless recognizes the overriding importance of these data,

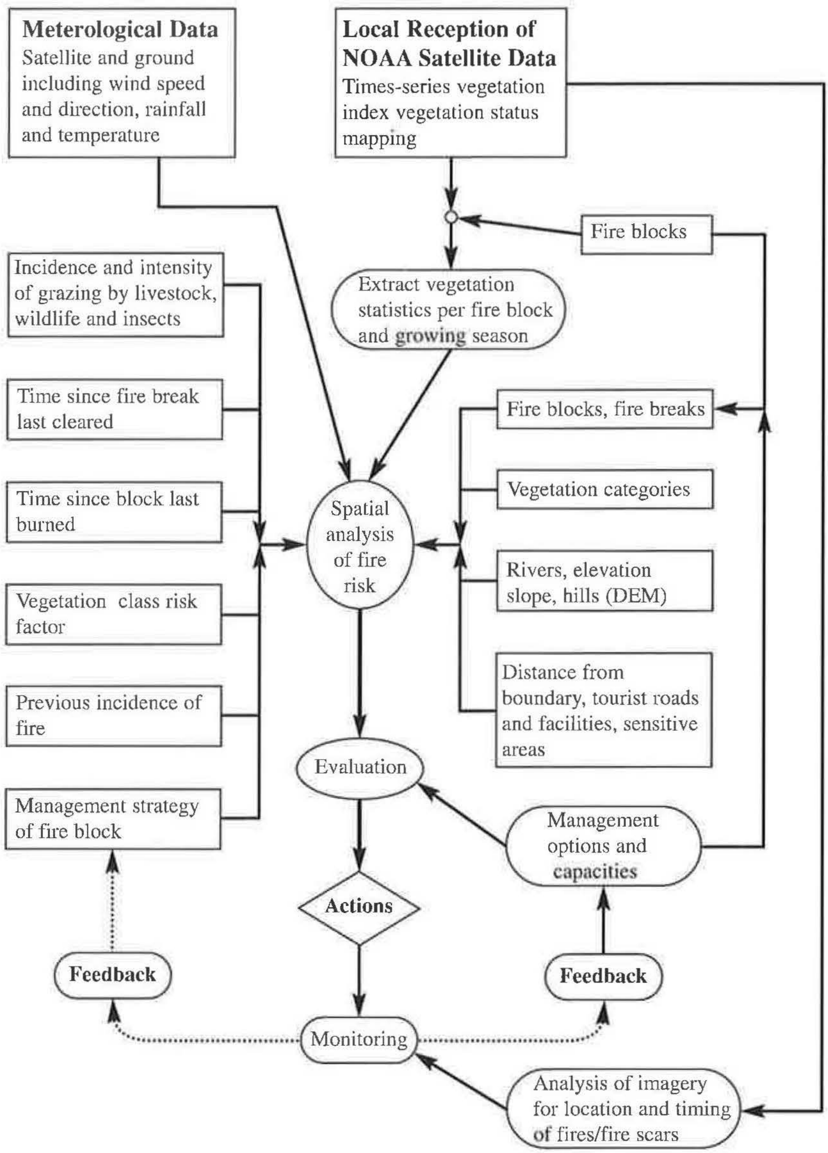

Figure 3 A model for fire risk assessment.

without which the utility of remote sensing in particular would be questionable. A study of vegetation change in the Mara, Kenya, in relation to livestock distribution and the distribution of Masai pastoralists was carried out using a combination of aerial photography, Landsat imagery, reconnaissance flights and ground sampling (Lamprey, 1986). Results indicated that *Acacia–Commiphora* woodlands and the tsetse flies associated with these woodlands declined rapidly as a result of Masai burning. Studies such as these, illustrate the need for a range of different data sources in analysing cause and effect but also show the importance of ground surveys.

Global positioning systems

Whilst ground surveys form an essential component of the overall DSS, reasonably accurate geo-referencing of these data is essential if they are to be combined with remote sensing and GIS-based information. GPS are space-based radio positioning systems that provide 24 hour, three-dimensional position, velocity and time information to suitably equipped users anywhere on or near the surface of the Earth. The NAVSTAR system, operated by the US Department of Defence, is the first GPS system widely available to civilian users.

GPS is a three-dimensional navigational positioning system. Using multiple satellites and hyperbolic geometry it determines the position of a receiver in three dimensions – effectively providing longitude, latitude and altitude. Receivers calculate the position and elevation of the receiving antenna, at any time of day, anywhere in the world, on land, at sea, or in the air. Applications for GPS are now numerous. Marine vessels, military and civilian, are important users. GPS is widely used for coastal, channel and harbour navigation, as well as for navigation over the oceans. GPS is also applied to aircraft navigation but is increasingly being used for land-based navigation and position fixing. By recording information from GPS receivers, positional information can also be transferred to other sources of electronic information, including databases, GIS and mapping systems. However, in order to assess their utility as a part of a DSS, it is important that current limitations to GPS accuracy are clearly understood.

Civilian users use the Standard Positioning System (SPS) without charge or restrictions. The US Department of Defence intentionally degrades SPS accuracy by the use of Selective Availability (SA). As a result, predictable accuracy of SPS is given as 100 m horizontal and 156 m vertical (Federal Radionavigation Plan, 1995). These figures express the value of two standard deviations (95% accuracy) of radial error from the actual antenna position to position estimates made under specified conditions: satellite elevation angle (>5 degrees) and PDOP[1] (<6). The effect of SA can be illustrated by the following examples.

In a study of the accuracy of hand-held GPS receivers (d'Eon, 1995), single fix positions, which can take less than a minute to obtain, provided better than 100 m accuracy more than 80% of the time (i.e. 20% of the time the positional error was greater than 100 m). Allowing the receiver to collect fixes continuously for 15 to 30 minutes and averaging them gave a median position error of 17 m. Campbell (unpublished data) recorded 182 000 position fixes at 1-second intervals at a single point and averaged these for each minute of recording. Figure 4 illustrates the errors in positioning obtained. Some of these averaged positions were still more than 100 m away from the true location. The probability of being within 15 m of the true location was only about 20%. Differential GPS (DGPS) techniques are capable of position fixes with less than 1-m error, although these systems are more costly to implement. In addition to errors due to SA, careful consideration of

[1] Position Dilution of Precision, an indicator of geometric error of GPS position.

(a)

(b)

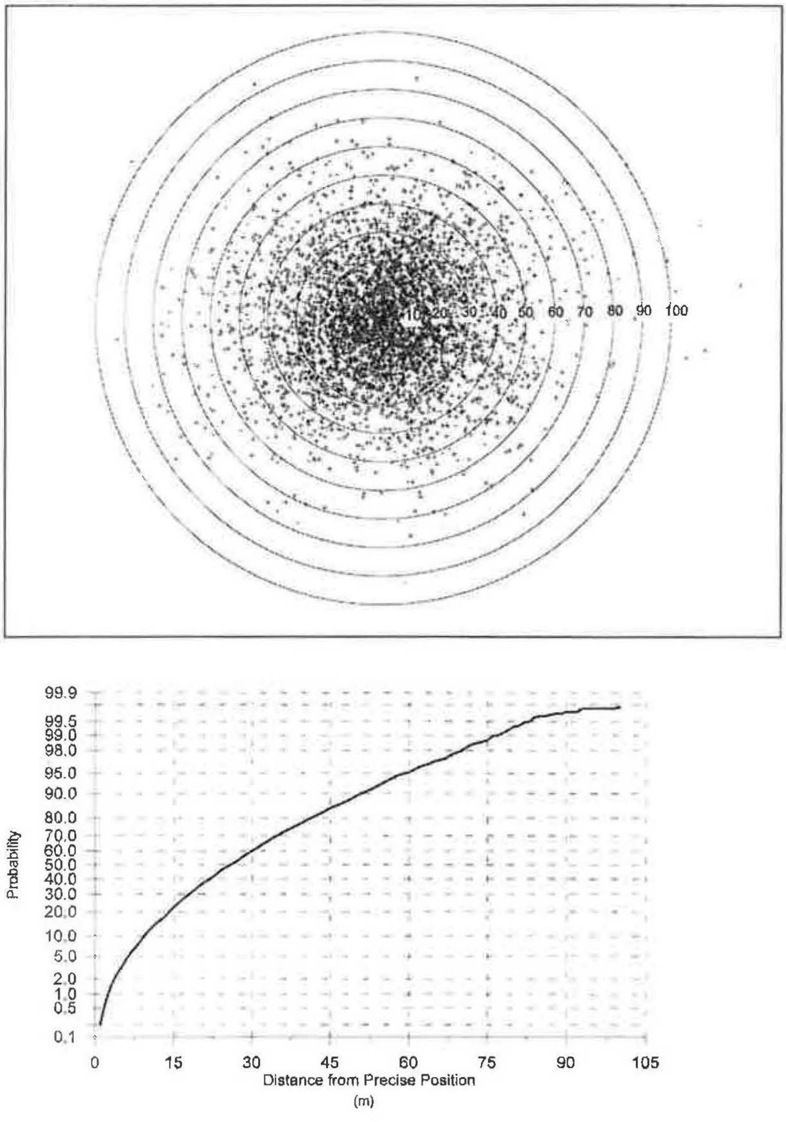

Figure 4 Illustration of potential errors in GPS positioning due to Selective Availability. (a) Spatial distribution of individual fixes, each point representing the average of 60 position fixes recorded at 1-second intervals. Circles represent distance from precise (DGPS) position in metres. (b) Probability plot of errors in the same set of GPS position fixes.

co-ordinate systems and geodetic datums is required. Incorrect use of datums can, for example, introduce errors greater than 1 km.

Given these levels of accuracy, field surveys can now relate, as standard operating procedure, data obtained through either observation or measurement to geographical positions, although margins of error need to be considered carefully when integrating GPS-derived data with other sources of spatial information in a GIS. GPS data can be entered in databases, either following field surveys or, directly in the field through the use of portable data recorders. In the Okavango area of Botswana, as part of a DFID-supported project, locations of tsetse traps are routinely recorded using GPS and this information integrated with a GIS-based database (G. Slade, personal communication; R. Allsopp, personal communication). Remotely sensed and other sources of data can then be directly compared with trap locations, facilitating management decisions.

Geographical information systems

The technological development of GIS and remote sensing began as separate disciplines, but their combined capabilities represent an important development of DSS for NR development (Loh and Power, 1993). Although their individual characteristics have presented problems of integration, recent advances in the software have greatly facilitated the use of these technologies in information systems. In order to carry out the analysis required for strategic planning at regional levels against tsetse and trypanosomiasis in sub-Saharan Africa, the Food and Agriculture Organization of the United Nations (FAO) is developing a GIS on tsetse and agriculture (Hursey and Slingenbergh, 1995). GIS is also used in a number of tsetse control programmes, as illustrated by the following examples.

Studies have shown that incorporation of satellite imagery in a GIS combined with ground data on fly density and environmental conditions can be used to predict favourable vector habitats in sites difficult or costly to reach on the ground. Kitron (1996) used Landsat TM imagery combined with ground-based environmental data integrated in a GIS to identify factors associated with local variations of fly density and to determine the number and location of fly suppression traps required by a local control programme. The development and use of GIS to assist trypanosomiasis control was also examined by Perry *et al.* (1994) and by Rogers (1994) who approached a number of issues, including: strategic research, conceptual models, research approach, GIS database acquisition and development, GIS hardware and software, and data analysis.

A DSS facilitating the implementation of trypanosomiasis control can be constructed by mapping a number of variables including vegetation classes and land use in general. Digital images from satellites with high spatial resolution provide a source of information that is both accurate and synoptic for producing these maps when combined with brief but specific field surveys. A case study (de Wispelaere and de Wispelaere, 1994) which examined the Adamawa plateau in Cameroon, illustrated results obtained by processing SPOT satellite data for the mapping of vegetation classes and land use in a region infested with *Glossina morsitans submorsitans*. Results were integrated in a GIS adapted for a programme of combating tsetse.

An information systems approach was adopted by the Trypanosomiasis Control Project in Togo. This involved systematic, grid-based sampling to correlate a wide range of data relevant to understanding the impact of the disease and to planning intervention (Hendrickx and Napala, 1995). Data collected through field surveys were related to NOAA satellite image data (a 10-year time-series of 10-day maximum value composite NDVI imagery) as well as to existing data sources on land use and demography. The information obtained through spatial analysis using GIS indicated practical methods for control.

Academic tools?

Whilst these examples clearly illustrate the potential power and usefulness of decision support tools in tsetse-related studies, there remains little published literature linking remote sensing, aerial surveys, GPS and GIS for the management of tsetse control and development of policies in areas either cleared of tsetse or where the vectors are controlled at low densities. A computer-aided literature search yielded 1331 publications between 1979 and 1996 with relevance to tsetse (CAB International Publishing, 1979–96, *Abstracts on Agriculture*). Of these, only 8 references mentioned GIS (within title or abstract) and a total of 18 referred to GIS and/or satellite remote sensing. In contrast 261 mentioned 'traps/trapping', 204 mentioned 'chemical control', 96 dealt with 'genetics/DNA', whilst only 13 referred to 'environmental impact'. The scarcity of references in the literature to tsetse, GIS and remote sensing indicate that these technologies have yet to become integrated, in an operational manner, in land use planning and management in tsetse control areas, but remain as largely academic tools.

Does this imply that issues of control are foremost in the minds of those working with tsetse, and that the wider consequences of control, resulting rural development issues and problems, and the wider issues of tsetse control as a component of development have received little consideration? The fact that only 13 out of the 1331 publications referred to environmental impact suggests that this may indeed be the case.

Both GIS, GPS and remote sensing represent tools that can be applied to a wide range of topics relevant to tsetse control areas. This includes livestock numbers, distribution and carrying capacity, vegetation characterization and identification of potential tsetse habitat, mapping local tsetse densities, human settlement and agriculture, and real-time environmental monitoring of factors, such as fire, to name but a few. It is suggested that without the widespread utilization of these DSS tools, tsetse control, whilst becoming more sophisticated, is in danger of becoming increasingly out of touch with other activities in a rapidly changing scene of social, economic and environment development.

INFORMATION MANAGEMENT

Decision-making in NR management is an information-intensive task and in many cases it is the ability to assimilate pertinent information into the decision-making process that emerges as a limiting factor in resource management (Loh and Rykiel, 1992). In some cases there is little information on which to base decisions. In other situations, the sheer mass of data makes it difficult to use. With the advance of information technology, a range of computer tools of increasing complexity, including GIS and remote sensing, are more widely available. To ensure that these tools are used as effectively as possible in planning and decision-making, the next step is a framework within which different tools combine to produce an integrated resource management system capable of supporting decisions. As awareness of the potential benefits of DSS technology increases among NR managers and donors, demands for such systems will grow and the following important issues need to be considered.

- Provision of information to managers and policy groups in a format in which it can be best understood and used. Information, together with the formats in which the data are stored, must, therefore, be designed with resource management problems in mind. Although a great deal of information has been collected through various research programmes, in many cases this information is not directly relevant to management problems.

- Information monitoring needs to be targeted towards specific problems. If an assessment is to be made of the performance of particular management strategies, this assessment will only be of practical value if it is made in terms that relate to the objectives of decision-makers.

- A clear understanding of inherent limitations of the information is necessary. The errors, biases and underlying resolution of all data sources need to be documented and understood.

- Unnecessary complexity is a hindrance and will delay utilization of the data, or cause it not to be used at all. All users of the system should not have to become GIS and remote sensing experts in order to access information held by the system and its associated databases.

- Data flows across platforms or systems and between individuals should be simply accomplished. If not, different data sources are likely to be used in isolation from each other. This includes aspects such as field data collection using GPS, aerial survey, satellite imagery, and the incorporation of ancillary data from other sources, such as national census, as well as the more 'mechanical' aspects, such as translation between different file formats. Of particular importance is easy access to comprehensive and up-to-date metadata summarizing all aspects of a project's information holdings and outputs.

In order to accomplish this, resource managers and decision-makers themselves need to become *users* of the relevant information systems and to provide the feedback essential in turning information technology into operationally useful systems. Moreover, for DSS to become effective, systems must not only be technically correct but must also be designed to allow for human and organizational constraints. A number of considerations listed by Stuth and Smith (1993) are relevant to this issue:

- successful exploitation of information technology depends on the ability and willingness of personnel in an organization to use the appropriate technology to engage in worthwhile tasks

- the design target must be to create a socio-technical system capable of serving organizational needs, not to create a system capable of delivering a technical service

- the design of effective socio-technical systems will depend on the participation of all relevant 'stakeholders' in the design process

- benefits will only result if systems are directed at opportunities or problems that need to be resolved

- information technology systems must be designed to serve the functional needs of an organization by serving the functional needs of individual users in practical and acceptable ways

- the exploitation of the capacity of information technology can only be achieved by a progressive, planned form of evolutionary growth and, to be successful, design concepts must as far as possible complement existing procedures.

The use of computerized systems of data management and data mapping does not automatically mean that these systems need to be complex and costly. On the contrary, the more complex a system, the greater the chance that it will *not* be incorporated within standard operating procedures. Successful data management, therefore, needs to present a simple and easily understood user interface.

CONCLUSION

Information systems are now reaching an evolutionary point where decision support professionals can contribute to the decision-making process in a manner and within a time-frame likely to improve the quality of decisions made. However, embracing remote sensing, GPS and GIS as tools within a DSS may take time and requires a gradual process of change and adaptation from existing systems of decision-making. The key challenge is to improve decision-making and provide better support for stakeholders. Within a DSS, information support needs to accomplish three tasks: (a) recognize the nature of decisions required, (b) provide information on alternatives, and (c) facilitate verification and follow-up on actions taken. Within the field of natural resources, remote sensing, GIS and GPS tools are perhaps uniquely placed to fulfil the second and third of these. They are also able to assist in providing much of the background information required to develop an improved understanding of the problems in the first place and thus of the nature of decisions required.

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Chapter 9

TOWARDS COHERENCE IN DEVELOPMENTAL DECISION-MAKING: THE DECISION SUPPORT ROLES OF REMOTE SENSING AND GIS – LESSONS FROM THE LARST APPROACH

Jim Williams

INTRODUCTION

Ever growing pressure on natural resources and the environment requires better decision-making if development is to be sustainable. Today's increasingly complex environmental decisions are more likely to be effective if they are based on reliable and well-organized information (see Dalal-Clayton and Dent, 1993) for examples of developmental decision-making not based on reliable resource data). In many developing countries, however, existing data networks are often fragmented, weak, and of only vestigial relevance; the technical institutions concerned have difficulties adapting to rapidly changing needs. The result is a downward spiral of under-funding and ineffectiveness, from which it is difficult to escape.

While the technologies of the information society, including remote sensing and geographical information systems (GIS), offer unprecedented opportunities for enhancing environment monitoring capabilities, they do require proper utilization of outputs if they are to be effective. *Better and more information does not automatically lead to better decisions, better plans or better management.* Experiences have shown that problems of policy and weak institutional structure, capacity and sustainability, also need to be addressed if there is to be proper return on investment in data and information supply. Too often the missing ingredient is a system of prioritized decision support.

This chapter examines some of these issues in relation to the objectives and activities of the Department for International Development (DFID)-supported Local Application of Remote Sensing Techniques (LARST) approach to resource management. LARST works with institutions in developing countries to use low-cost satellite data and appropriate GIS tools, as part of the process of meeting decision-makers' needs for timely and appropriate environmental information, at affordable cost. (The term 'environmental information' is used generically to cover many aspects of information on the state of our bio-physical environment.)

As we progress into the new information society the whole character of decision-making, and the importance of environmental information is undergoing radical change. For example, in many countries:

- previous data scarcity is rapidly changing into data overload
- rates of change in resource use and resulting environmental impact are getting ever more pressing
- routine monitoring and evaluation is a high priority need, for example, for regular policy updates
- decisions increasingly need up-to-date information for contingency response management
- greater coherence in policies, strategies and activities is expected from all participants
- decision responsibilities are increasingly being devolved to district and community level.

Overall, the need for good information management skills, both within and between institutions, is becoming critically important, but this does not happen easily nor by itself. Changes as profound as these need to be thought through at the concept stage in the project cycle, and provision made for institutional development in line with changing needs and capacities. After all, environmental monitoring is a one-way long-term process. If mankind has a long-term future then so does environmental monitoring. Consequently we need to plan strategically to maximize benefit in terms of better decisions across the whole spectrum from least outlay, or be prepared to invest more sector by sector.

WHY A COHERENT APPROACH TO ENVIRONMENTAL INFORMATION IS IMPORTANT

Sustainable development involves the highly inter-linked domains of natural resource management, environmental protection, disaster mitigation, and people. Reliable and easily accessible environmental information is essential for a number of functions within these domains including: policy formulation, strategic planning, resource allocation and development investment, day-to-day management, legal regulation, together with monitoring progress and impact assessment for policy revision. Increasing pressures on limited natural resources demand a continuous effort to monitor the qualitative and quantitative characteristics of the resource base and related environmental conditions, and in order to service these different decision levels in consistent and coherent ways, and so minimize internal conflict and confusion. In other words, using the same data sets to monitor progress as to set policy, is likely to have more coherence in decision-making than using one source of data to set policy, another to manage the resource, and yet another to monitor progress and evaluate impact.

Good governance

The utilization of accurate and up-to-date environmental information is an essential ingredient of the competence of governments to formulate sound policies, and make timely decisions. The political and executive elements of government can only be held fully accountable for their actions if relevant information is available in the public domain. Both developing country and donor agencies increasingly need environmental information throughout the project cycle, and particularly at the feasibility and impact assessment stages, to provide evidence that policies and investments are having substantial, positive impacts. Post-implementation monitoring and auditing may be needed to measure sustainability.

Problems with environmental information projects

Despite the importance of environmental information, the record of environmental information system (EIS) projects is poor. Typical problems (for more detail see Hassan and Hutchison (1992) or CTA (1995) include:

- failure to identify priority user needs at the outset
- technicians processing data have often failed to pass on information to potential users
- data not provided on a timely basis or in an easily understandable form
- the inadequate capacity of the intended user to make effective use of the information
- co-ordination problems between different institutions
- overlapping institutional mandates
- misunderstandings between information suppliers and users
- barriers to information exchange of a technical, political or financial nature
- sustainability: technical, financial and institutional, and especially retention of skilled personnel.

Improving effectiveness

The effectiveness and sustainability of environmental information provision can, however, be greatly increased by applying the lessons of recent experience, and ensuring that:

- all components of EIS are geared to meeting users' priority needs
- users have the mandate, political will and resources to act on the information generated
- national and local ownership of the system is strong through the participation of all stakeholders
- all information required (e.g. social and economic data) can be made available
- efforts start at an appropriate level and demonstrate early 'success' to participants
- effective institutional and policy development is included, notably for public sector bodies.

Thus, to ensure that development is both effective and sustainable a coherent approach to environmental information is absolutely essential. There are so many participators and so many decision points in the complex process, that coherent and consistent decision-making is impossible without a sufficiency of shared environmental information. But how is this coherence and consistency to be developed? Who pays? Who leads? Who co-ordinates? Who controls quality? Who ensures free exchange of data sets? Which comes first, the decision-maker or the information?

TOWARDS INTEGRATED ENVIRONMENTAL MONITORING

Sectoral fragmentation

Although the importance of information in the evolving globalized society might merit examination of the whole process of national data collection, information management and decision support, the majority of attempts are often limited to specific aspects in a single sector, which are often difficult to rectify and sustain in isolation. Donors tend to prefer projects that are relatively narrowly focused but, with relatively little co-ordination between activities, this almost inevitably results in reduced potential benefits. This loss is likely to be particularly acute in policy formulation and higher level decision-making where effective cross-sectoral integration is most important. Modern information tools are available to overcome this lack of coherence, if the political will exists to make use of them. This need for a more integrated approach is underlined by development of national environmental action plans (NEAPs as promoted by the World Bank) and the United Nations Environmental Programme (UNEP) State of the Environment reporting, in both of which monitoring and evaluation play important roles and justify concerted efforts towards effective EIS.

Multistage approach

In the 'multistage' approach to survey and mapping of environmental and natural resources, different tools are employed at different levels of detail. Depending on the nature of the application, overview data, such as satellite imagery, are used in an initial analysis: they may be processed using a computer or interpreted manually. The initial analysis helps to identify where nested pockets of more detailed information are required. Increasingly higher resolution data are used to provide greater detail, with the process usually ending in ground sampling. "Since increases in scale are costly, the multistage approach is highly efficient, providing information at a high level of detail at relatively low cost" (Hassan and Hutchinson, 1992). This approach also improves timeliness and does not rely on only one information source, which may fail to provide the necessary results.

Multiple use

Multiple application of data is one aspect of system integration. For example, where meteorological departments utilize Meteosat and NOAA satellite-derived data, it is possible to supply data and products developed for one purpose, to other users for different but related purposes. EIS are thus capable of multiple applications. For instance NOAA normalized difference vegetation index (NDVI) data might be supplied by the meteorological services to agricultural departments for crop monitoring, to veterinary departments for monitoring range conditions, to wildlife departments for protected area management and to forestry departments to provide regular overviews of an area subject to fire. In turn these departments may have access to other data sets, for example, periodic high resolution satellite images, geo-referenced for vegetation type. The two entirely different data sets can be interfaced for regular analysis. For different aspects of natural resource management, different data combinations and interfaces will be required.

Integration

Environmental decision-making tends to be fragmented and compartmentalized. To be more effective and more sustainable, development activities must be more integrated. The principal areas where more integration is needed are:

- multidisciplinary: data from different sectors need to be analysed and assessed together
- temporal: resource dynamics, rates of change need be identified for timely intervention
- spatial: local resources need to be integrated within a consistent spatial overview
- institutional (horizontal) integration refers to decision-makers at any given level exchanging information with each other, and using EIS data sets that are consistent
- institutional (vertical) integration refers to decision-makers at different levels (national, provincial, district and community) exchanging environmental information with each other, and using data sets that are consistent, one to the other. This also includes developing consistency between policy, planning, resource management and regulation which is another form of integration, however, this is not integration of information, but of government functions.

Clearly, appropriate levels of integration will depend on the nature of the resource management issues at hand, but also in the levels of technical and institutional capacity in any particular case. In general terms, however, an interdisciplinary approach is essential, and there have been widespread calls in recent years for greater integration of biophysical and socio-economic data sets (e.g. in Agenda 21 and the Convention on Desertification). In addition it should be clear that sharing of information between users increases the potential benefits from any one data source. The most successful example perhaps is the Indian multi-sectoral National Natural Resource Management System which was used to justify investment in a national space programme, products from which are now being used successfully on previously intractable development problems, through their nation-wide Integrated Mission for Sustainable Development (e.g. see Rao, 1995).

SATELLITE REMOTE SENSING AND GIS

Developing countries are likely to be disadvantaged by the information revolution unless they have access to technology appropriate to their particular information management processes. For the purposes of improving management of environmental information, PC-based satellite remote sensing and GIS stand out as having paramount potential.

Satellite remote sensing

The number, range and capability of remote sensing satellites are growing steadily. These high flying instruments provide images or other kinds of data on the state of land, water and atmosphere. Some provide free data transmitted directly, others only provide data through commercial sales, still others are restricted for military purposes. Remote sensing is a powerful technology, especially when used in conjunction with ground data sets in GIS for detecting and understanding environmental changes. Factors in developing countries that make satellite imagery particularly useful include:

- existing data generation networks tend to be weak, slow and expensive to sustain
- individual decision-makers tend to be responsible for large areas, often difficult to access
- resource use tends to be extensive rather than intensive
- seasonal variability tends to be of greater importance in many tropical areas
- greater vulnerability to natural disasters requires a rapid overview for timely intervention.

Geographical information systems

GIS are computer systems with special software designed to manage geographical and other data sets to produce useful information (e.g. thematic and relational maps, tables or graphs). GIS have three important components, computer hardware, computer software and a proper organizational context (database). The GIS software comprises powerful sets of computer tools that can store, retrieve, integrate, transform, analyse and display spatial data (Woodfine, 1995), according to the decision need.

One of the great advantages of a GIS is its ability to integrate data from a variety of sources: this characteristic can also provide a major impetus to interdisciplinary collaboration. Maps and data related to spatial maps are increasingly being converted into computer readable formats which can then be integrated with the digital data obtained from satellites. Socio-economic and infrastructural data can also be stored within a GIS. Personal computers are now sufficiently powerful to support useful GIS, and the combination, PC-GIS, is increasingly appropriate for a growing number of applications in developed and developing countries alike.

Local Application of Remote Sensing Techniques

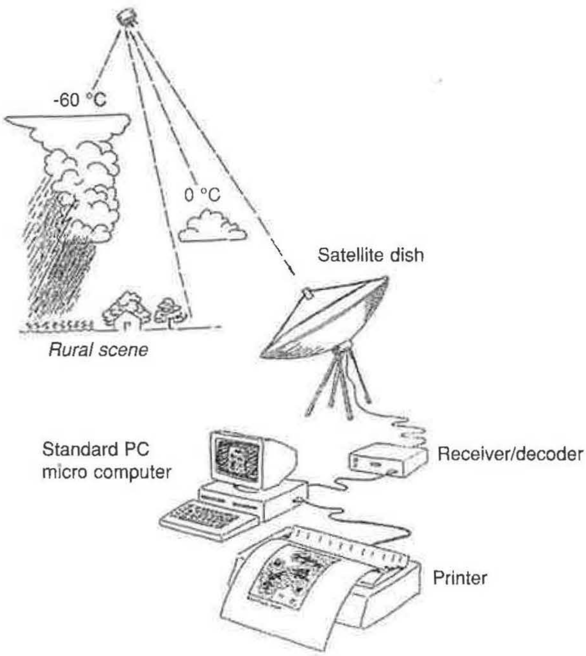
The LARST approach seeks to help improve local decision-making processes by empowering local resource managers with routine and timely access to remotely sensed data appropriate to their needs, and by developing local capacities to make best use of the information derived.

Many of the operational meteorological satellites broadcast their data for users to 'capture' and use immediately, without charge. Since 1988 inexpensive PC-based receivers have been available for users to receive and process these data, which are useful for monitoring the changing state of land, sea and atmosphere.

This 'real-time' data can be useful for obtaining a current overview of the state of the whole resource (e.g. the whole lake, or rangeland, or watershed) together with an assessment of how quickly the situation is changing. (Data from meteorological satellites are usually frequent, every hour or every day depending on the satellite, but provide only coarse resolution (kilometres) images with little spatial detail.) Such timely large area overviews are often so difficult and expensive to obtain in any other way, as to be totally impractical. Through direct reception from the satellite, data are routinely available when required, at very low running cost. LARST technology is designed to enable persons to link their PCs to the desired satellite data stream, and so obtain, process and use the data appropriate to their requirements, in a routine, straightforward and cost-effective way. The technology comprises hardware and software: Figure 1 shows LARST Meteosat (a) and NOAA receiver systems (b). Most, but not all such projects have involved the national meteorological service as interface institution because of the important role of weather in environmental monitoring.

The LARST 'timely overview' approach differs from most other approaches to the use of satellite data in important ways. A large majority of conventional remote sensing projects concentrate on maximizing spatial detail and downplay the important time element in information usage. Such activities use high resolution data, which are expensive and frequently difficult to obtain in developing countries, to map resource variation in detail for 'planning' purposes. In many such instances though, planning and response processes are weak so few of these activities are cost effective, and all are notoriously difficult for institutions in developing countries to sustain.

(a)



(b)

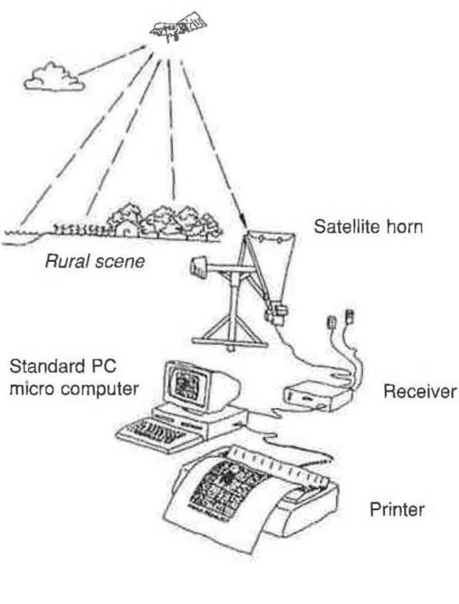


Figure 1 (a) Meteosat: European geostationary satellite above Equator and Greenwich Meridian intersect; (b) NOAA: American polar orbiting satellite.

Basic tools using meteorological satellite

- Rainfall estimation: rainfall over an area can be estimated from hourly observations of storm cloud dynamics. This works best over a period of several days in conjunction with available rain-gauge data, and is useful for identifying potential flood or drought situations. It is particularly helpful for monitoring rainfall over neighbouring countries and predicting river flows in international watersheds, where timely surface observations are often unavailable.
- Vegetation state: the changing quality (i.e. greenness) of vegetation can be monitored through seasonal cycles enabling agricultural production, rangeland productivity or plant state (for biodiversity value) to be tracked over the whole country or region. This information provides the basis for many (drought) early warning systems.

- Fisheries state: the surface water temperature patterns of sea or lake change with the weather (wind) and satellite temperature imagery can be useful for understanding the changing state of a whole fishery and likely short and long-term effects on productivity.

- Fire: satellite thermal imagery can detect vegetation fires, cloud permitting. Using different satellite data and depending on the circumstances, fire risk, fire, occurrence, fire movement, fire frequency and fire extent can all be measured, as it burns. Since the majority of fires are caused by man, fire occurrence may be a good indicator of, for example, intrusion and settlement in a protected area. Where management practices are introduced to minimize fire, for example, in forest areas, satellite fire detection can be an objective indicator of progress.

- Agrometeorology: several surface variables can be estimated from satellites so enabling rational interpolation of, for example, agricultural conditions between sparse agrometeorological stations.

- Tracking and data relay: where required data collected on the ground can be relayed via satellite for early warning of changes, for example, volcano state monitoring, and in the case of moving animals or fishing vessels with radio transmitters, their location can be determined.

These basic tools may be used individually, or in combination to help address more complex tasks where timely understanding and/or prompt responses may be required, such as:

- drought early warning: using area rainfall, vegetation–crop yield estimation

- river basin or wetland management: using rainfall, vegetation, standing water, fire

- forest management: using fire risk/occurrence/area, state of the forest

- protected area (and rangeland) management:vegetation, rainfall, fire risk/occurrence/extent/frequency, animal tracking, water point conditions
- agricultural yield prediction, and determination of outbreak areas for crop and animal pests and diseases including malaria, through local agrometeorological and vegetation conditions
- lake/fishery/coastal zone management: using sea surface temperature (surface dynamics, i.e. up-welling, currents), gross primary productivity (surface chlorophyll and phytoplankton), surface turbidity (estuarine emissions) as well as rainfall and vegetation state in coastal zone and watersheds.

Remote sensing together with GIS

One of the most effective ways for resource managers to make use of some of the vast amount of data that streams from these free satellites every day is to develop a GIS to help inform and support their priority decisions employing the pertinent parts of the satellite data stream. Thus, for example, where forest fires are a problem (Figure 2), if a GIS is developed with data sets of land use, forest characteristics, ecosystem vulnerability, population, village distribution, administrative boundaries, etc., then the daily fire data is set in context, and can be used more effectively for:

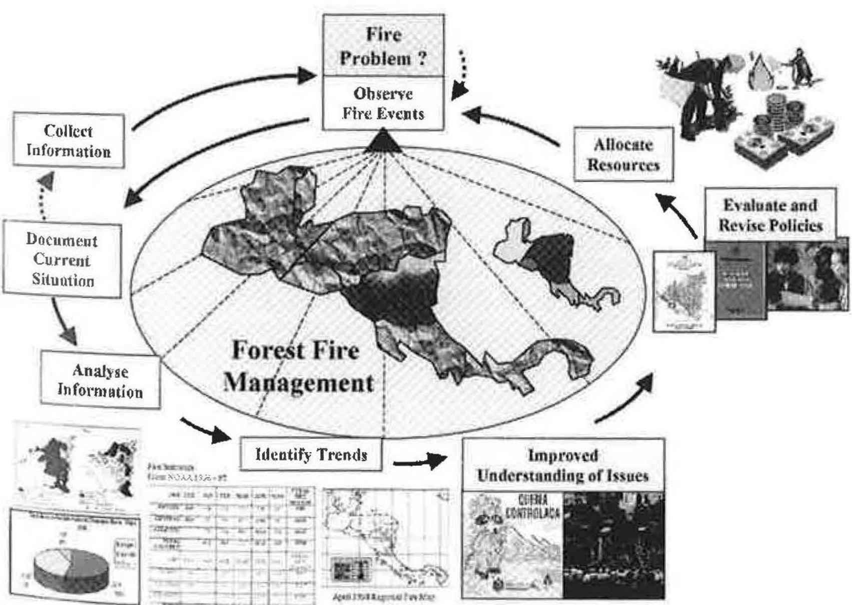


Figure 2 LARST real-time Forest Fire Monitoring System developed in Nicaragua and Indonesia.

- policy decisions: which areas are priorities for protection at national or local level?
- planning decisions: how many of the priorities can be protected with existing resources?
- investment decisions: where and when should new fire breaks be constructed?
- management decisions: fires in that area need immediate investigation and follow up
- regulation: too many fires in an area invalidates the concession
- monitoring and evaluation: how effective was an education campaign in reducing fire?
- understanding: research on fire ecology and loss of biodiversity needs fire occurrence data.

INSTITUTIONAL ISSUES

LARST aims to help people in existing institutions to meet both ongoing and new responsibilities through improved staff utilization. Nearly all formal LARST links are with government institutions, and most of them are with meteorological services. While in all cases the technical capacity of recipient institutions is enhanced, it is expected that staff and institutions should be able to increase their operational outputs using LARST techniques without the need for new staff. The more that the new techniques fit in with institutional mandates, practices and objectives, the more incentive there should be to maintain the new technology and sustain outputs. In practice, other institutional factors so complicate the picture that finding or creating the optimal institutional environment for LARST is often the most crucial issue affecting operational sustainability. A fundamental problem facing many institutions in developing countries is that they have failed or been unable to evolve sufficiently to keep up with changing times. LARST direct reception of satellite data is part of the 1990s data explosion and information revolution that is changing our world so rapidly. Only 20 years ago this technology was unimaginable. That institutions designed to function with 1950s technology can cope with this technology at all, is encouraging. It is hardly surprising if a measure of more rapid institutional development might be required to ensure more effective capacity utilization.

Some of the range of institutional obstacles that affect the use of environmental information were raised earlier (see EOS (1996) for amplification); LARST seeks ways to overcome them. There is a need to effect reform in positive, constructive and sustainable ways, appropriate to the particular circumstances, refocusing institutions to engender effective decision-making. Among the obstacles, the most important ones found specifically to affect the effectiveness and sustainability of remote sensing and GIS as operational tools are explored below, towards identifying more appropriate institutional frameworks for the future. Constraints include:

- poor interdepartmental relations affecting communications and collaboration
- weak decision chain: poor flow of information from data gathering to decision-maker
- overlapping mandates of 'competing' institutions
- outdated mandates and working practices: status quo rules: the need for modernization
- lack of resources to establish and sustain monitoring activities
- owning and organizing data: too much effort is spent on collecting and archiving data, not enough on processing, distributing and using
- government structure: (de)centralization and subsidiarity
- security concerns: information used to be power, now the driver is the 'expiry date'
- dependence on strong, informed leadership
- status of organizations, users and research: capacity utilization rather than capacity development as well as related human resource issues including education and training, staff retention and continuity (as the difficulty of retaining capable persons with good computer skills in government).

While GIS/EIS can be highly cost effective (see Tveital, 1993), the kind of practical problems which bedevil many initiatives have been explored in depth at several recent workshops and symposia (e.g. van Genderen, 1992; CTA, 1995), together with issues related to the development and integration of *local* GIS to facilitate incorporation of community interests into both short and longer term development processes (CTA, 1997).

FUTURE COMPATIBILITY

The world is changing rapidly and profoundly, in part as a consequence of the ongoing revolution in information and communication technology. Two related trends of major pertinence here are:

- the explosion of environmental data which has already swamped the capacity of government institutions in many countries, and which can only get more difficult as new satellites and other data sources produce ever larger amounts of detailed data, which through cheap global communications are available to all
- decentralization of developmental decision-making whereby the role of central government changes and the importance of addressing complex local problems is more appropriately addressed through local decision-making processes.

These trends re-emphasize the importance of developing a data strategy and an integrated information framework within which pertinent data can be managed effectively at both national and local levels. LARST attempts to provide an outline for the development of this framework making use of existing institutions and the relatively inexpensive, personal-scale technologies like the PC (and PC-based remote sensing and GIS) which lend so much power to those people and institutions who learn to use them effectively.

Since government technical institutions can be slow to change, however, it seems likely that the future role of non-governmental information service providers will be much enhanced, particularly for participatory decision support at local level. LARST work with government meteorological services showed the great potential of such institutions but also the lack of incentives for them to adapt and really provide optimal service. Decision-makers considering how best to strengthen national or local environmental decision-making would probably be best served through a public-private partnership somewhat along the lines of the US weather service (see Friday *et al.*, 1996). Where data policies are appropriate, lead government institutions working together with the private sector, NGOs, community-based organizations and academia, should be able to produce a sustainable EIS, which maximizes benefit through co-operation and is sufficiently flexible to grow with change. Future satellite data policies are moving to encourage the 'local information service provider' to be more enterprising in participating in this process, for example, see the new USA LANDSAT 7 data policy (Ellickson, 1998).

CONCLUSION

The need for effective decision support based on reliable environment monitoring can only grow. Future trends are towards more timely, complex and accountable decision-making to achieve sustainable development within the information society. The LARST approach to using free meteorological satellite data with GIS offers several advantages here, including:

- scale: regional, national and district, overview and perspective
- sectoral: multi-sector, multi pillars and major resources
- temporal: timely and longer term
- financial: optimal use of free data
- institutional: local reception on to PC empowering local institutions
- modular: PC-based so upgrades easily.

Given the cost of highly structured EIS and lack of financial resources available for environmental monitoring in developing countries, the LARST approach to remote sensing with integral GIS to merge with other data sets provides a framework for an appropriate national EIS that evolves and grows as circumstances demand and resources permit.

Developing a national EIS is a long-term evolving process, not a finite time-bound project, and it must continuously adapt to ensure:

- it is always up to date
- it is firmly focused on current priority needs for better information
- it is working with the most appropriate institutions, developing their roles accordingly
- optimal utilization of outputs is being derived at all times.

Thus, the vital need is to incorporate an integrated approach to environmental information into the project cycle planning process to foster wider acceptance and ownership by people and institutions concerned. When all is said and done, our common future lies in sustainable global development; a process that is critically dependent on effective integration of the many local and national activities, and this cannot be achieved without good information and its effective management.

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Chapter 10

REDUCING THE IMPACT OF DROUGHT IN SOUTHERN AFRICA – DELIVERING AND USING BETTER FORECASTS

Chris Sear

> "Drought is a normal part of southern Africa's climate and one of the most important natural disasters in southern Africa. In fact, it is becoming increasingly unusual for drought not to occur somewhere in southern Africa each year. The dependence of most of southern Africa's economies on rain-fed agriculture emphasizes the importance of drought early warning products for short and long-term decision-making in various sectors of the national economies of the region" (L. Unganai, *Drought Network News*, **6** (2): 7, 1994).

INTRODUCTION

We are all concerned about the weather. Even in temperate and generally well watered parts of the world, drought occasionally occurs and causes agricultural and economic disruption. In many parts of the tropics and sub-tropics, drought is a recurring problem at local, national and regional scales.

One such area is southern Africa. Climate variability is the single most important factor affecting the livelihoods of the people in the region but drought risk is not yet managed well in southern Africa. Much of the region is dry, making agricultural production especially vulnerable to drought. Drought affects some part of the region most years and several severe, regional scale events have occurred this century. Since 1980, four major drought events have reduced agriculture production significantly and disrupted national economies throughout the region. One of these events was in 1991–92, when devastating drought affected the region. More recently, in 1994–95, early and mid-season rains failed over most of the area. The El Niño-Southern Oscillation (ENSO) warm phase event which began in boreal spring 1997 (Webster and Palmer, 1997) threatened to bring another such drought to parts of southern Africa (Figure 1). However, whilst some parts of southern Africa had significant rainfall shortfalls in 1997–98, region-wide severe drought did not occur.

Concern is growing that drought might become more frequent in southern Africa because of global warming. If this occurs it will exacerbate problems for vulnerable households, communities and whole economies. Preparing for, and mitigating the effects of droughts that occur in the present climate through the

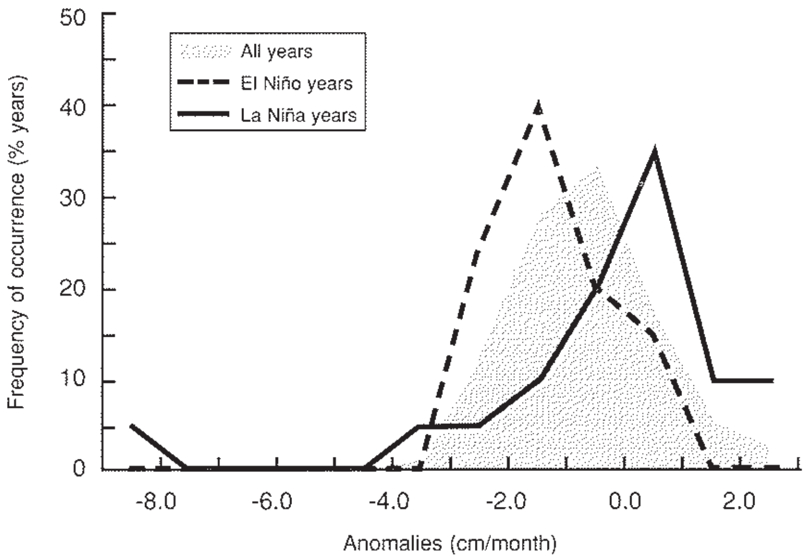

Figure 1 ENSO impact in southern Africa (30°S–13°S; 20°E–50°E): the relationship between ENSO events and regional rainfall anomalies (November–May 1890 to 1989). Figure taken from the International Research Institute Web Page [http://iri.ucsd.edu/hot_nino/impacts/safr/index.html]

development of improved early warning and coping strategies, are not only essential activities but could help reduce adverse impacts of future change, reducing climate-related vulnerability in the region.

Effects of drought

Drought affects all economic sectors. Here we concentrate on agriculture because of the pre-eminent role it plays in southern Africa. It makes a significant contribution to national gross domestic products and links strongly to other important economic sectors. The impact of drought varies between countries within the region, depending on their economic structure (Benson and Clay, 1998), but while some countries may be more resistant to drought than others, all countries in the region are adversely affected.

Drought effects in the agricultural sector are not limited to reduced food security through harvest failure, but also have impacts across societies, through worsened balance of payments, increased budget deficiency and consequent debt, higher inflation and reduced investment. The effects of one severe drought can be widely felt and long term. Agricultural communities live with the expectation and experience of drought. They have historically developed a range of strategies to adapt to these and to mitigate their effects. It should be noted that modern agricultural practices often tend to work against these traditional risk management strategies. Severe events can have a serious impact on these communities, increasing their vulnerability to poverty and threatening the longer term viability of their livelihoods and natural resource base.

The impacts of drought on small farmers include a reduction in household income and food availability, loss of capital and savings invested in livestock and increased social vulnerability as social support systems are undermined. The impacts are particularly acute for the poorest and those with the least developed social support links. In the worst cases, costly emergency responses have to be mounted but there may still be loss of life.

Drought can cause large economic losses at district, regional and national level through loss of crops and livestock and related processing and trading industries. Drought contingency planning and mitigation needs to be improved to reduce economic losses and the social and environmental impacts of drought. Some of the decision tools becoming available to ameliorate the impact of drought, by improving drought early warning and drought risk management are discussed below.

Improved early warning and drought mitigation

The recurring problem of drought has prompted efforts to improve early warning systems and to develop various mitigation or remedial interventions and contingency plans in advance of the event. The policy environment and the institutional context for these interventions are of great importance. The impact of drought on people's lives can be greatly influenced by the effectiveness of national and local institutions in increasing preparedness for drought. New developments in early warning systems and recent experiences in operating drought mitigation measures and contingency plans now provide the opportunity to develop improved drought contingency planning and implementation.

The prospects for earlier and more reliable warning of drought have improved significantly in recent years with advances in seasonal weather and climate forecasting as well as in monitoring rainfall and vegetation conditions from satellites. The inclusion and use of such information in a national early warning system for drought is discussed in Chapter 11.

Seasonal climate forecasting is now sufficiently reliable to be of operational use in agriculture, forestry, water and health sectors in southern African countries. Problems inhibiting uptake include institutional blocks to dissemination and incomplete understanding of end-user needs (NRI, 1996). A regional forecasting forum has now been established, supported by national meteorological services, to co-ordinate the further development of services and links to information users. Other forms of early warning have also been developed in recent years and these also need to be validated for incorporation into contingency planning procedures (see, for example, Chapter 11). Long lead forecasts (defined here as greater than 1 week ahead) and improved systems for early warning of drought are now available. How can these technologies be transferred to drought-prone southern Africa?

ENSO and southern Africa

Most seasonal forecasting techniques are ENSO-based. The relationship between ENSO and African rainfall is now well enough known and the regionalization of global forecast models is sufficiently reliable, that seasonal rainfall can now be forecast some months ahead with useful reliability (Barnston, 1994; Cane *et al.*, 1994; Mason, 1995; Makarau and Jury, 1997). In the near future at least, scientific advances in long lead forecasting will continue to occur primarily at global centres, with regional and local nuances added by scientists in each region. Thus, good communication and information flow between global and regional centres will be vital.

Southern African climate is strongly influenced by ENSO. A link between ENSO and southern African rains has been generally accepted for some years (Figure 1). Major warming in the eastern tropical Pacific (warm period ENSO or El Niño events) is associated with reduced rainfall over much of southern Africa during the following summer's rainy season, whereas good rains are known to often follow cool period ENSO (La Niña) events (Figure 1). Recent studies have suggested that ENSO is probably the strongest determinant of the overall character of southern African rains (for example, Makarau and Jury, 1997). However, conditions in the Pacific are not simply warm or cold. Neither does El Niño simply switch on and off.

ENSO events vary in time, space and intensity, with wide fluctuations, both within and between seasons and, therefore, individual ENSO events vary in impact. Not every El Niño is followed by drought in southern Africa and not all La Niña events are followed by good rains everywhere in the region. ENSO effects are always moderated by more local conditions, for example, South Atlantic and Indian Ocean sea surface temperature patterns. These directly affect southern Africa rainfall patterns (Makarau and Jury, 1997). This highlights a major concern. For effective delivery of reliable, regional and sub-regional climate forecasts, local knowledge must add value to the products generated at global centres. Regional and national forecasts must be 'owned' and delivered regionally and nationally.

The recent increased frequency and severity of both El Niño events and southern African droughts (1982–83, 1987–88, 1991–92, 1994–95, 1997–98[1]) has led to increasing concern over the future climate of the region in a warmer world. Modelling experiments have suggested that ENSO events may be more common and more severe in a warmer world and also that by the middle of the 21st century, southern Africa will be warmer and on average drier that at present (WMO, 1995). Increased variability (leading to more frequent and severe floods and droughts) may be a feature of a warming world. If this turns out to be the case, then the current trend towards more frequent and severe droughts in the region might be

[1] Strong El Niño warm phase in the Pacific but no severe drought in most of southern Africa.

expected to continue. Whether or not this scenario actually occurs, today's droughts are problem enough and improved drought risk management will increase the region's ability to cope with what the future brings.

Forecast time-scales

Available techniques promise increasingly reliable predictions of future weather and climatic conditions in southern Africa. We can classify these long lead forecasts by time-scale:

- multiyear climate forecasting (more than 1 year ahead)
- seasonal forecasting (3 months to 1 year ahead), based on ENSO forecasts
- within-season, long range weather forecasting (1 week to 3 months ahead)

The present skill base and forecasting activities in southern Africa provide realizable opportunities to improve forecasts on all these time-scales (see Sear (1996) for mid-1990s analysis). There is an increasing recognition that these technologies can and must be used more effectively to the benefit of all members of societies in sensitive, drought-prone regions.

Long lead forecasting

Long lead forecasting is potentially more reliable in the tropics and sub-tropics than in middle latitudes (Palmer and Anderson, 1994). This is because of the relatively simpler weather regimes that dominate tropical climates in most seasons and because of the strong influence of ENSO on inter-annual variations in the tropics. Indeed:

> "The dominant mode of inter-annual variability of the tropical ocean-atmosphere system associated with ENSO appears to be predictable with lead times of several seasons. In general, the theoretical basis for seasonal predictability of larger scale circulation in the tropics is well founded" (WMO, 1995).

Reliable long lead climate forecasts are now becoming available through rapid progress towards an understanding of seasonal and inter-annual climate variation. These long lead forecasts are generated by global climate research centres. Also, improved weather forecast modelling techniques and study of local climate influences are now offered by global meteorological centres and can be used to increase the reliability of forecasts on time-scales of days to weeks.

Focusing forecasting effort on ENSO, modulation of the ENSO signal and the relationship between global scale forcing and regional rainfall patterns, promises further significant improvement in long lead forecasting over the next few years. This advance will, we believe, be delivered by global centres but can only improve forecasting for southern Africa, if scientists in the region are involved, adding local knowledge. How then can these techniques be transferred, delivered and taken up in southern Africa?

The need is clear: reliable and timely long lead forecasts, owned within the region and delivered through regional and national organizations. Delivery should be free and equitable and end-users should be empowered to create demand for appropriate products and to take up and use them. Then, improved forecasting can be used as a decision tool.

FORECAST REQUIREMENTS FOR BETTER DROUGHT RISK MANAGEMENT

Weather forecasts only have value when they are used. Until now, long lead forecasts have had little, if any influence on drought risk management. The main reason for this lack of uptake is *not* that potential users do not appreciate better forecasts; the potential value of reliable forecasts is widely appreciated (NRI, 1996). However, potential users, from farmers to governments, do not yet have confidence in the reliability of the forecasts.

The absence of reliable predictions of drought or forecasts of rainfall variations is a major source of uncertainty that encourages inaction at all levels of society. If reliable forecasts were used, then they could have a profound effect on drought risk management in southern Africa. This is now widely appreciated in the region by governments and donors, however, commercial and subsistence farmers and the public are still somewhat sceptical (NRI, 1996).

There is now a real interest in the prospect of making use of improved forecasts. Forecasts in each of the three time-scales (multiyear, seasonal and within-season) have distinct applications and benefits in the southern African agricultural sector, as they do in other sectors, including commercial forestry, water resource management and health (NOAA OGP, 1997).

The needs of agriculture

Tables 1 to 3 summarize the usefulness of multiyear, seasonal and within-season forecasts as perceived by the agricultural sector in southern Africa. The tables represent a synthesis of responses to formal questionnaires and informal discussions with the various groups in 1995 (Gibberd, 1996).

Multiyear forecasts

Reliable multiyear climate forecasts, providing an indication of the quality of each of the following few wet seasons (dry/wet), could significantly reduce a major element of uncertainty in long-term planning and thus facilitate preparations for, and execution of, better policies, plans and investments (Table 1). For example, decision-makers, from commercial farmers to governments, would be less constrained to make decisions based on past experience alone. Improved multiyear forecasts would also enable better development and sectoral planning. They would assist in the development of Structural Adjustment Policies (SAPs) and other strategic plans, such as 5 or 10-year agricultural strategies. Improved multiyear forecasts would also encourage responsible government, facilitating long-term drought preparedness and mitigation strategies. From the point of view of the user, the essential characteristic of take-up is not the degree of quantitative and spatial precision of the 5 or 10-year forecast but rather its overall reliability. Unfortunately, the success or reliability of such forecasts cannot be judged for some years, which severely limits their uptake.

At the subsistence farm level, the impact of improved multiyear climate forecasts is expected to be minimal. Small farmers tend to be risk averse, assuming each rains will be normal and in general do not take account of long-term change. Commercial farmers and large producers plan more strategically but the next season interests them much more than conditions over the following 5 or 10 years.

Seasonal forecasts

The ability to predict, with confidence, the quality of the next wet season is, without doubt, the single most sought after climate information for drought preparedness and risk management (Rook, 1996). A reliable forecast (dry/normal/wet), issued some 3 to 6 months ahead of the season, has a wide range of immediately useful applications with quantifiable benefits. Take-up would result in enhanced food security at regional and national levels and reduced risk of crop failure and risk from the effects of crop failure at national and local levels. Farmers want and need better seasonal forecasts (Table 2). Both subsistence farmers and commercial enterprises would like to be able to plan better for the forthcoming season. Presently, subsistence farmers plan (hope) for good rains. How can these forecasts be delivered and taken up? For many, one answer is an effective extension service, which can translate seasonal forecasts into useful and timely advice at individual farm level. For others, dissemination via the media (especially over the radio) is the answer.

Improved seasonal forecasts, together with increased understanding of the effects of drought on the agricultural sector and economy, will for the first time, enable governments to take into account rainfall and climate variability in their macro-economic policies. Reliable seasonal forecasts will encourage greater trade in agricultural commodities and most importantly, will enable countries to improve national food security, whilst reducing expensive grain reserves.

In southern Africa, experimental and maturing regional and national early warning systems (EWS) will benefit greatly from the transfer of technologies that deliver reliable seasonal forecasts. Early warning systems could be transformed. The Southern Africa Development Community (SADC) Food Security Technical and Administrative Unit (FSTAU) Regional Early Warning System (REWS) is not yet a key component in an integrated regional approach to drought risk management

Table 1 Need for multiyear forecasts in agriculture

Activity		**Influenced by forecast departures from normal**		**Scale of forecast**	**Response**
Crop research	Plant breeding and agronomy	Rainfall (amount and distribution) Temperature	75%	10 years	Select for maturity period, yield plasticity; Test different farming systems, crop geometry, manuring, spacing, etc.
Forestry	Plantation establishment	Temperature Rainfall	80%	10 years	Species choice, spacing in plantation
Seed production	Strategy	Rainfall	80%	5–10 years	Choice of appropriate ranges of crops and varieties
	Bulking	Rainfall – below normal	80%	2–5 years	Secure irrigated sites
Plantation and orchard crops	Establishment	Rainfall Temperature Humidity	80%	5–10 years	Choice of crop and site
Irrigation	Development	Rain	80%	5–10 years	Size of dam, spillway, capacity of pumps, reticulation, area to be irrigated
Drought recovery	Subsidies	Rain	50%	2–5 years	Issue appropriate seeds; distribute hardy small stock, donkey sets, hafirs and other water conservation measures
Community action		Rain	50%	2–5 years	Labour-intensive projects in roads, dams, wells, land clearing, afforestation
Livestock management	Herd size	Rain	75%	5–10 years	Culling policy, retention of young females in herd, grazing development
Management of national herd (cattle)		Rain – below average	50%	2–10 years	Establish protected holding grounds for immature and young females intercepted from slaughter market

Source: Adapted from Gibberd (1996).

but aims to become so. The FSTAU objectives include the provision of adequate food to meet the needs of individual households and the total population of the region (Farmer, 1996). There is a clear role for improved seasonal forecasts, through better drought risk management, to help to deliver this objective.

The FSTAU REWS works regionally and is based in Harare. It currently provides governments, donors and NGOs with some early warning of the likely impact of climate on harvest prospects. Delivery of reliable seasonal forecasts to the REWS should enable it to release earlier and more accurate assessments of harvest prospects, food availability and import needs. In order for the REWS to operate more effectively, it must be able to work with national meteorological services and with national EWS in the region.

Improved seasonal forecasts could empower both national and regional EWS to act as real tools for drought preparedness and mitigation. The information supplied to government by EWS could then be accepted (trusted) and would be taken up, strongly influencing government decision-making. For example, if a seasonal forecast indicated a late starting and short wet season, the regional and national EWS could issue timely advice to government, extension services, commercial support services and the public, suggesting the use of early maturing and drought-tolerant varieties in marginal areas. An example of an improving national EWS from Botswana is described in Chapter 11.

Within-season forecasts

Improvements in within-season forecasting offer the least utility at national and regional scales because the time-scale of these forecasts does not provide much scope for decision-making. Once the growing season has started there is little chance for policy-makers to intervene, except in emergency situations. Agrometeorological modelling is one application, however, which would benefit immediately from improved within-season forecasting, leading to improved crop yield forecasting.

On the farm, however, improved within-season forecasts would be very useful, as indicated in Table 3. How can better within-season forecasts be disseminated reliably and equitably to all farmers? One answer is via the media. More easily understood (user-friendly) weather forecasts, issued over the radio (and television) could be taken up readily by every farmer in the region. One approach that has already been tried successfully in some areas is providing weather and environmental information and farming advice, through entertainment programming, such as in plays and soap operas. One such was a recent radio soap opera in Kenya, aimed at women living in rural areas and funded by the Department for International Development (DFID). In this way, important information to aid the decision-making process can reach all members of even isolated communities, including women.

Table 2 Need for seasonal forecasts for farmers

Weather feature	Farmers able to use prediction	Response area	Lead time required	Minimum precision/ accuracy required
Drought	A,B,C	1. To farm/not to farm 2. Choice of crops and tillage systems 3. Contingency plans – livestock 4. Contingency plans – water supplies	3 months	90%
Overall quality of rainy season	A,B,C	1. Choice of crops, crop varieties and tillage systems 2. Irrigation planning to use impounded water efficiently 3. Arrange appropriate seasonal credit	3 months	80%
Planting rains – date	A,B,C	Timing of field operations *NB Actual planting date has a highly significant effect on yield*	0.5–1 month	80%
Planting rains – nature	A,B,C	Whether to risk dry planting	0.5 month	80%
Mid-season drought – start date	B,C	Choice of variety and planting date	3 months	80%
Mid-season drought – length	B,C	Choice of crop	3 months	60%
Mid-season drought – severity	B,C	Preparing to divert grain crops to fodder	3 months	60%
End of rainy season – date	A,B,C	1. Timing of harvest operations 2. Possibility of late catchcrops 3. Plan post-harvest tillage	2 months	80%
Winter rains – amount	B,C	1. Plan summer crops for optimum winter cereal crop 2. Possibility of other winter crops	6 months	80%
Winter rains – distribution	B,C	Level of inputs to invest in winter crop	1 month	60%
Frost – first frost date	A,B,C	1. Planting date for late planted crops 2. Cut off planting date for frost-sensitive crops	6 months	80%

Frost – last frost date	C	1. Date of winter cereal planting to avoid frost at anthesis 2. Planning spring plantings under irrigation	6 months	80%
Frost – frequency over winter	C	Preparedness for frost on winter horticultural crops	1 month	40%
Dry season – severity	A,B,C	1. Off-season farm capital development activities 2. Livestock management	1 month	40%
Dry season – length	A,B,C	1. Disposal of crop residues 2. Fodder rationing to livestock 3. Move livestock if necessary	1 month	40%
Temperature – above normal summer	C	Precautions: dairying, horticulture	3 months	60%
Temperature – below normal winter	C	Precautions: small stock, horticulture	3 months	40%

Source: Adapted from Gibberd (1996).

Types of farmer: A = subsistence farmers; B = 'emerging farmers'; C = commercial farmers.
Precision/accuracy: 100% = completely reliable; 0% = same as having no forecast at all.
* Weather: convectional, i.e. highly variable spatially and temporally, dry planting risky or frontal, i.e. widespread, penetrating rains, dry planting advised.

Table 3 Need for within-season forecasts for farmers

Common farming operation	**Key weather feature(s)**	**Lead time**	**Minimum precision required**	**Response**
Planting – seeds	Rain	1–3 days	80%	Timing
– transplanting	Rain	1–3 days	95%	"
Fodder – hay making	Dry weather	1–3 days	95%	Timing
– silage making	Dry weather	1–3 days	80%	"
Spraying – terrestrial	Dry weather and wind	1–2 days	80%	Timing
– aerial	Dry weather and wind	1 day	95%	"
– animals	Dry weather and wind	1–2 days	80%	"
General)– top dressing	Rain	1–3 days	80%	Timing
field)– weeding	Dry weather	1–3 days	80%	"
operations)– inter-row cultivation	Dry weather	1–3 days	60%	"
Reaping – tobacco	Prolonged dry weather	3 days	80%	Accelerate reaping
– cotton	Rain	3 days	80%	Accelerate reaping
– coffee	Rain	1–3 days	80%	Avoid CBD areas
Insertion of inter-crop into a widely spaced cereal crop	Prolonged late rains	3–7 days	80%	Plant it
Irrigation	Past evapo-transpiration data	1 week	80%	Adjust irrigation schedule
	expected	1 week	80%	
Release of predator agents in IPM	Various	1–3 days	<95%	Follow instructions

ANOMALY FORECASTING				
Smoke generation or ultra-low precipitation sprinkling of horticultural crops	Night frost	>12 hour	80%	Light fires, start sprinklers in night
Moving animals to higher ground, reinforcing water management structures, moving pumps back from river banks	Unusually heavy rain	>12 hour	80%	
Blight control in potatoes and tomatoes	High humidity	1 week	80%	Apply prophylactic sprays

Source: Adapted from Gibberd (1996).

Summary of agricultural needs

The needs of agriculture are summarized in Table 4. Seasonal and multiyear forecasts have an immediate and considerable utility in agriculture. While producing better within-season forecasts clearly would make an impact in agriculture, other sectors might benefit more. The questions that need addressing now are concerned not with how the forecasts are used by, for example, farmers, but rather, how can such information be disseminated equitably to all to enable uptake? Figure 2 summarizes the problem. In the following section we consider the decision boxes on the left of Figure 2 and how to overcome blockages that prevent information flow to the right.

SUSTAINABLE DROUGHT RISK MANAGEMENT

Removing obstacles to uptake

Forecasts have no value at all unless they are used. Between a seasonal forecast becoming available and being used there are a number of potential obstacles to uptake. The information flow in Figure 2 has six clear decision points:

1. Is the forecast issued?
2. Does the forecast meet user needs?
3. Does the user know what action to take, based on the forecast?
4. Is the market environment conducive to uptake?
5. Does the user have sufficient resources to use the forecast?
6. Does the user take action, based on the forecast?

Here current progress in delivering seasonal forecasts in southern Africa is considered, leading to answering *yes* at the first three of these decision points but bearing in mind the need to raise awareness of the potential value to users and providers alike, and the questions:

- Who owns the service of forecast provision?
- Who adds value to the forecasts and who owns the forecast products?
- Who delivers the forecast and to whom?
- How are user needs assessed?
- How can use be encouraged?
- How can the benefits of improved forecast be quantified?

Is the forecast issued?

Global scale forecasting is rapidly improving. Improvements in the reliability of global scale forecasts are being made by the large international centres, such as the new International Research Institute for Seasonal-to-interannual Climate Prediction (IRISCP) in the USA, the UK Meteorological Office (UKMO) and South African Weather Bureau (SAWB). From the perspective of global provider, Carson (1997) rightly considered the dissemination of seasonal forecasts to be a

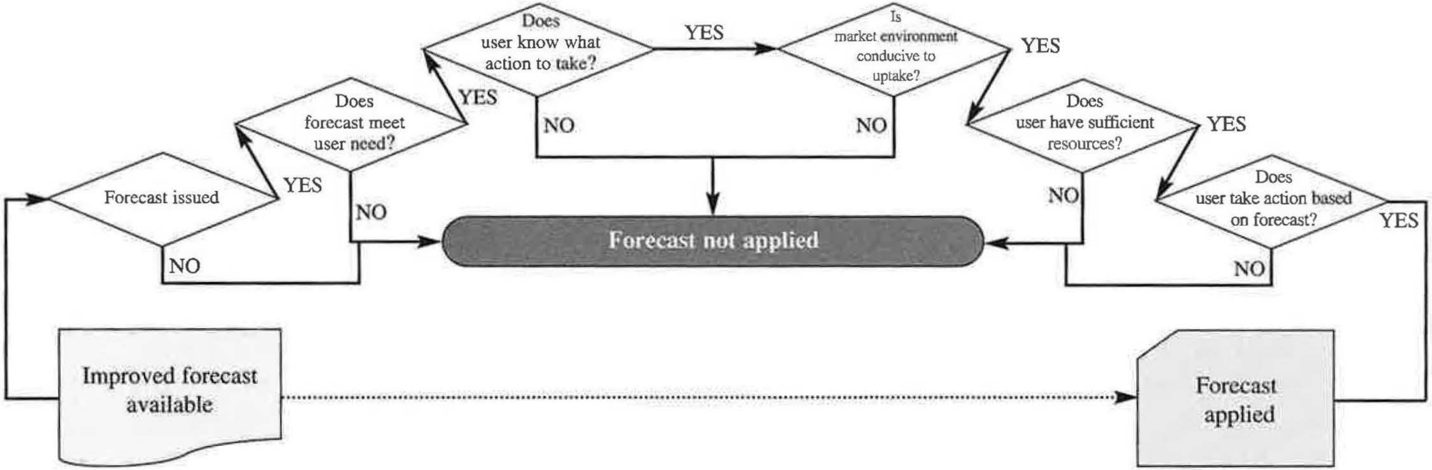

Figure 2 Improving the quality of forecasts alone does not guarantee that they will be applied. *Source*: Adapted from NRI (1998).

Table 4 Summary of forecast needs for agriculture

User group	Forecast	Usefulness	Benefit	Assumptions
Subsistence farmers	Multiyear	Limited: risk-averse	Reduced risk of food shortage and famine, improved food security in poor years, increased marketable surpluses in good years	Forecasts and environmental information freely available to, and understood by all, effective extension service, effective agricultural support services, effective response of (commodity) marketplace in good years
	Seasonal	Useful: planting dates, crop/variety selection		
	Within-season	Limited: harvesting date		
Commercial farmers	Multiyear	Strategic planning, plant and capital investment decisions	Reduced risk, improved financial viability, increased comparative advantage	Effective agricultural support services, individual resources, effective marketing environment
	Seasonal	Tactical planning, marketing, planting areas and dates, crop/variety selection, water management		
	Within-season	Water management, inputs application, harvesting dates		
Agricultural services	Multiyear	Strategic planning, plant and capital investment decisions, production strategies	Improved financial viability, more rapid response to farmers' needs (local, national and regional)	Effective marketing environment, company resources and farmers' financial viability
	Seasonal	Tactical planning, product selection, marketing, pricing policy		
	Within-season	Marketing tactics, product switching		

Extension services	*Multiyear*	Strategic planning for drought mitigation, development of improved advice	Better extension service to subsistence farmers and smallholders	Government support to extension service, effective management
	Seasonal	Development of specific advice and arrangements for promulgation		
	Within-season	Dynamic adjustment to advice and delivery		
Commodity exchanges	Multiyear	Limited: long-term futures	Increased trading potential within region and globally, improved ability to cope with domestic shortfalls, reduced need for government intervention (freer market)	Efficient market environment
	Seasonal	Forward and futures market pricing		
	Within-season	Forward and futures market pricing		
Early warning systems	Multiyear	Limited	Improved forecast information to users, earlier and more accurate assessments of crop yield, harvest, food availability and price, deficit, surplus and import needs made possible	Uptake and use of information supplied by government and other end-users
	Seasonal	Monitoring conditions on the ground, crop yield forecasting, fire risk analysis, drought preparedness advice		
	Within-season	Agrometeorological and crop yield modelling, fire and fire risk management		

Strategic grain reserves	Multiyear	Strategic planning	More effective strategic grain reserve policy	Timely and reliable early warnings are made available to government
	Seasonal	Strategic planning, building reserves		
	Within-season	Tactical planning for support and food distribution		
Government planners	Multiyear	National and sectoral planning and policy	Better governance, improved food security and more sustained economic growth, improved ability to mitigate drought effects	Awareness of drought risk, international considerations
	Seasonal	Financial policy		
	Within-season	Limited		

Source: Adapted from NRI (1996).

sensitive and difficult issue, going beyond the science and the technology to include political and socio-economic concerns. He highlighted a time lag between the production of seasonal forecasts (in this case, at the UKMO) and possible use, stating:

> "The forecasts are first sent to the National Meteorological Services (NMSs) and closely related agencies of the regions involved. In this way our forecasting efforts attempt to enhance rather than undermine the position and credibility of these NMSs. Then after a delay of 2–4 weeks they are sent to specific international agencies, other institutes and collaborating scientists. They are placed fully in the public domain at a later date ... "

Carson noted that an undeveloped aspect of the whole procedure is getting critical feedback from the agencies receiving forecasts. To continue to improve forecasting, global providers needed to know how the forecasts are interpreted and used by recipients and for what applications? Are they used to provide products for third parties and what value do agencies and ultimate end-users place on the products? Carson even asked: "is **any** use in fact made of the forecasts?" He noted that the UKMO had solicited feedback from recipients with only limited success. He concluded:

> "I believe that the overriding aim, in a purely humanitarian context, should be to: *reach those who stand to benefit most, with a product of potential value, which can be understood and used, and which is timely and not held up or otherwise constrained by politics, bureaucracy or commercial interests.*"

Global forecasting centres could issue regular and frequent forecasting bulletins freely and distribute them, for example, via the internet. This type of distribution has already begun. They could establish a routine of issuing rolling forecasts. Fixed time-span seasonal forecasts could be reviewed and adjusted regularly in order to minimize shock effects of irregular, sudden or unexpected forecasts. Thus, in an ideal world, forecast delivery could be as shown in Table 5.

Table 5 Forecast delivery

Forecast frequency	Time span (lead)	Nature
Multiyear Annual or bi-annual	3, 5 and 10 years	Rolling
Seasonal Monthly	Growing season	Fixed
Within-season Daily and weekly	5–30 days	Rolling

The problems with this model are not at the global centres, nor with the forecasts. The problems are of ownership, of blockages to delivery and of equitable distribution.

Ongoing activities – ensuring forecast issue and uptake

In 1995, the US National Oceanic and Atmospheric Administration, Office of Global Programs (NOAA OGP) considered that regional applications centres would be required to disseminate IRISCP forecast products to end-users in drought-prone regions. NRI's previous analysis showed clearly that in southern Africa such an agenda, while worthwhile, was too limited (Williams, 1996). It would do little to encourage feedback from end-users in several sectors (especially agriculture and particularly small farmers) as to their forecast needs. Neither would it facilitate national ownership of the forecast products and their equitable dissemination. We considered that this would promote isolation of the global forecasting community from end-users, thus encouraging a continued technological lead, as well as fragmentation and disintegration of local and regional expertise.

Significantly, the NRI study team concluded that to ensure uptake of the new forecast techniques available, national meteorological services in southern Africa – the traditional promulgators of weather forecasts on all time-scales – would need to reassess their roles as providers of weather and environmental information to government and public. This was especially important in the light of improved forecasting techniques being available at global centres and in view of the possible future regional dominance of the SAWB.

Thus, the global forecasting community recognized that their improved seasonal forecasts were not being made available in southern Africa and thus not taken up and used in the region. Thus also, most of the national meteorological services in southern Africa recognized the need for their involvement in the forecasting process (making global and regional seasonal forecasts more locally specific and products usable by end-users in their countries).

During the last few years noteworthy progress has been made in issuing forecasts, as demonstrated by the proliferation of forecast and ancillary information available on the internet. An early part of this process was a workshop organized in Zimbabwe in September 1996. Four working groups (comprising real active and potential end-users, national meteorologists and global climate forecasters) considered user information needs and delivery requirements for forestry, water resources, health and agriculture (NOAA OGP, 1997). The workshop participants concluded that end-user requirements for better forecasts covered all time-scales from days to decades. They recommended that the interests and needs of forecast end-users must be fully taken into account in the generation and dissemination of seasonal forecasts and that potential users of forecast information must be involved in the generation of appropriate products for local use. Thus, it was then clear that improved multiyear, seasonal and within-season forecasts and improved delivery were needed.

The workshop also confirmed the need to set up a regional forecasting forum to provide local and national scale knowledge to enhance and focus global forecasts. It was hoped that this would result in consensus seasonal forecasts being issued for the region. Such a forum would draw on a previous initiative in South Africa (South Africa Long Lead Forecasting Forum - SALLFF), on the regional global change System for Analysis Research and Training (START) initiative. Meteorological services in the region began to accept that they needed to re-affirm their pivotal roles in national data collection, analysis and product generation for local take-up. The Zimbabwe workshop was the first step in a continuing effort to issue and tailor consensus forecasts, throughout the world. This is being lead by the US NOAA OGP, and has had significant European funding. The chronology of this initiative, started in southern Africa, is described in NOAA OGP (1999).

In 1997 the Southern Africa Regional Climate Outlook Forum (SARCOF) was formed and met in Zimbabwe in early September to produce consensus forecasts for the coming wet season. Immediately following the workshop, the consensus forecast was made available, both to individual SADC national meteorological services for onward promulgation, and via the internet. In December 1997, a further meeting was held in Namibia to assess the first September forecast and its dissemination and *use* in the region and to adjust (or correct) that issued for the second half of the season, covering January to March 1998. The success of the forecasts and their uptake was analysed with some users in May 1998 at a further meeting in South Africa. This SARCOF process of forecast, adjust and analyse has continued during the past 1998–99 season in southern Africa and in several other drought-prone regions (NOAA OGP, 1999).

So, the answer to the first question is: yes the forecast is issued. In 1997, for the first time, a consensus seasonal forecast was agreed by international, regional and national actors and issued before the 1997–98 wet season. Forecast issue continues and will do, even without increasing regional and national ownership, because the global forecasting community will use modern communication media freely to deliver untargeted, unfocused predictions using the internet. These are picked up by the press, radio and television media and disseminated widely. Equity demands that efforts continue to ensure that the forecasts agree with each other, are appropriately worded and useful to all. So, making a forecast available via the internet and to national meteorological services is only part of the answer.

Does the forecast reach the user?

A reliable seasonal forecast is a potentially valuable decision tool in all sectors, at all levels of society and throughout the world. The 1996-vintage vision was for regionally owned, nationally enhanced and distributed seasonal weather forecasts that are applied locally by informed end-users in several sectors and which provide real, measurable benefits throughout the region. Thus would the value to the community of the available information be maximized.

Most national meteorological services in southern Africa appeared in 1996 to be incapable of realizing the full potential of their regional and global links: they needed capacity building investment (NRI, 1996). The benefit of improved long lead forecasts would not be fully realized without a number of concurrent developments across the economy. The report concluded that a broad, multidisciplinary implementation was needed for maximum impact and benefit. Furthermore, it was argued that benefits from the better management of strategic grain reserves alone would justify the necessary investment.

In Namibia in December 1997, several NMSs reported on their forecast dissemination activities. These activities showed promise as some customers (forecast users) were being trained in the meaning of the consensus forecast for their country and their specific needs, but the relative weakness of several of the meteorological services was apparent. To answer the questions that Carson (1997) raised, the continued weakness of meteorological services in southern Africa still needs addressing urgently. NMS fragility is a major potential constraint on the delivery and uptake of the newly available forecast information. Reliable drought warning may be economically and socially beneficial, but such information must be easily accessible and understandable for timely decision-making at all levels. This requires better capacity utilization in national meteorological services.

Until African NMSs are strengthened, blockages to free distribution of forecasts will remain in the region. NMSs need strengthening to encourage their participation in the forecasting process, their ownership of the forecast products, their adding value to the products (adding local specificity) and effective liaison with users and potential users, listening to user requirements and adjusting forecasts to meet them.

Does the forecast meet user needs?

Earlier in this chapter end-user forecast needs in agriculture were summarized. The challenge now is to work to meet those needs. As indicated above, issuing a forecast does not ensure uptake. The second step is to ensure that forecasts are provided which are tuned to the needs of a variety of users and are locally specific. How can this be achieved? What mechanisms can be used to deliver forecasts and other early warning information more effectively to a range of end-users? These questions are now being addressed by the forecasting and user communities in the region, through analysis of activities during this first season of consensus forecasting. The next steps for agriculture (and other sectors) will need to include focused participatory research in the region. This will determine end-user access and uptake (if any) of the available seasonal forecasts. It will determine real end-user needs and thus will be able to feedback end-user demand, through NMSs, to enhance the impact of improved forecasts as they evolve. This will close the circle for this potentially valuable decision tool.

One way of making better use of forecasts, providing a more focused delivery of environment information by a meteorological service, is for meteorological services to interact with users through formal early warning structures. This can facilitate the regular delivery of forecasts (question 1), as well formalizing their products, tailoring them to user needs (question 2) and helping users to decide what, if any, actions they can or should take (question 3). This is discussed in Chapter 11.

CONCLUSION

Drought is a recurring problem in southern Africa. Severe drought has an impact on all societies in the region, particularly through the agricultural sector. Long lead, seasonal climate forecasts are now becoming usable and have the potential to make a valuable contribution to reducing climate-related vulnerability in the region. These forecasts are based mainly on global scientific advancement but must be delivered nationally and locally in terms that are understandable and usable by the mass of the population and specifically, by farming communities.

There are many potential benefits of focused forecasts to the agricultural sector but there is a continuing need to promote activities aimed at overcoming institutional blockages to information flow that prevent uptake. These include improving forecast timeliness, accuracy and usability. It is especially clear that there is an urgent need to assess the needs of forecast end-users, especially small farmers.

In 1997, for the first time, consensus forecasts for southern Africa were issued and international activities begun which aim to improve the flow of information to forecast users. This will be achieved only by overcoming obstacles to the process and by empowering NMSs in the region to work with users to deliver more appropriate forecasts. The need is to address end-user requirements more fully and look at forecasts from the users' perspectives. It is hoped that these initiatives will reduce vulnerability in southern Africa to drought and other climate-related disasters. This will help decision-makers in the region to develop strategies to cope better with future climate change.

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Chapter 11

INTEGRATED DROUGHT EARLY WARNING – THE BOTSWANA EXAMPLE[1]

C. B. Sear, K. Campbell, D. Dambe[2] and G. Slade[3]

INTRODUCTION

Drought is a chronic problem in sub-Saharan Africa. Climate variability is the single most important factor affecting the livelihoods of the people in the region but drought risk is not yet well managed. Severe droughts in the 1980s and 1990s significantly reduced agricultural production and disrupted national economies. Concern is now growing that drought might become more frequent in the region as a result of global warming. If this occurs it will exacerbate problems for vulnerable households, communities and economies. Preparing for, and mitigating the effects of droughts occurring today are not only essential activities but could help reduce adverse impacts of future change. The problem of recurring droughts has prompted efforts to improve early warning systems (EWS) and integrated drought management. For example, increasing the drought preparedness of national and local institutions can mitigate the impact of drought on people's lives.

Today, drought forecasts are beginning to be useful, whether they are based on seasonal climate forecasts, or on a better appreciation of evolving conditions on the ground through the season. Improved drought forecasts require a focused and timely delivery of environmental information by a meteorological service. One way of making better use of drought forecasts is for meteorological services to interact with users through formal early warning structures. This can facilitate the regular delivery of forecasts as well as formalizing products, tailoring them to user needs and helping users decide what, if any, actions they can or should take. The Botswana drought EWS currently makes use of satellite-derived environmental information by integrating it with socio-economic data. In this chapter, we consider how the EWS has evolved in Botswana in recent years. We also look at how the system could be improved further and where it is a model of best practice that could be taken up elsewhere in sub-Saharan Africa.

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[1] Paper first presented as a Keynote Address at the Interdisciplinary Conference on Integrated Drought Management, Lessons for sub-Saharan Africa, Pretoria, South Africa, September 1999.

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THE BOTSWANA NATIONAL DROUGHT EARLY WARNING SYSTEM

Background

The Botswana national EWS for drought was initially set up on independence in the mid-1960s, at which time severe drought affected the country. It was set up to be a decision tool for central government to enhance drought preparedness, mitigation and management. The Government of Botswana took a pro-active approach when there was a general expectation of poor rains. Essentially the government wished to ensure that drought disasters did not cause death of its human or livestock populations. The initial focus of the system in the 1960s was on the livestock sector. Later, in the 1970s and 1980s the system was honed by successive drought emergencies, particularly in the early years of the 1980s, when a sequence of severe droughts ravaged the country

At the same time the focus of this system broadened to add arable agriculture, water and human affairs to the livestock emphasis. Indeed, through the 1970s and 1980s, emphasis was placed on sustaining arable agriculture as the driving force for the EWS. The Government of Botswana saw its drought EWS as part of the development process, with disaster management for drought being a humanitarian operation. It delivered fundamentally untargeted food relief to aid a large proportion of the rural population of the country. This system and its participants were expected to tap into and use existing information flows and not to start new formal structures. In this way the system was asked to build on strengths within various ministries. In the case of providing environmental information such as rainfall and conditions on the ground, the Department of Meteorological Services (DMS) was the primary, if not sole, data provider.

At first sight little has changed over the last three decades and the drought EWS in Botswana appears rather static. However, it has become especially efficient at delivering to high levels of government (the Rural Development Council – RDC, which reports to and advises the Office of the President) information that is *sufficient* for appropriate decision-making. Once drought is declared by the President, Botswana is very efficient at delivering food relief immediately (within days) to target populations. With 35 years experience this is hardly surprising, but Botswana is an unusual place in sub-Saharan Africa, in terms of its economy, its rapid development and its relatively large gross national product. Botswana is one of the five richest countries in Africa and can afford to insure that its population, its cattle and its seed grain are not destroyed by recurring droughts. Few countries in sub-Saharan Africa could afford such investment. While we can provide no financial confirmation here, we are confident that the limited investment described here provides good value for money. The benefit of prompt and efficient relief, following efficient information flow to aid decision-making, is great, in view of the potential cost resulting from not providing such.

On closer examination, the Botswana drought EWS is not static, it is slowly evolving, both as Botswana has become more capable of delivering relief and as it has begun to target relief more towards the most disadvantaged and vulnerable in its society. Thus, now is an opportune time to consider the workings of this system. The system as it operates today is described: how it is formally constructed and how links operate between the various participants; how information flows through this system; and how this information impacts on decision-making. In Botswana, such high level decision-making is primarily concerned with identifying drought, with assessment of the relief needed to mitigate and manage drought emergencies and with the question of how and where relief is distributed. 'When' is not an issue in this case, implementation of relief programmes is essentially instantaneous and efficient, upon the declaration of drought and lasts for at least 1 year thereafter.

Structure of the early warning system

The formal structure of the drought EWS operating in Botswana is shown in Figure 1. It is a hierarchical system in which information is gathered by various ministries and departments of these ministries and shared in the monthly meetings of the Early Warning Technical Committee (EWTC), the secretariat of which is provided by the Ministry of Finance. The EWTC advises the Inter-Ministerial Drought Committee (IMDC) which meets monthly or bi-monthly, depending on the time of year.

The IMDC is not a technical committee but has an advisory role. The IMDC secretariat is also provided by the Ministry of Finance and the committee advises the RDC on current environmental and socio-economic conditions throughout the country, recommending courses of action with respect to relief. The RDC is essentially the government decision-making body with responsibility to co-ordinate rural development initiatives. The RDC expects reliable information from the committees below it so that it can make sensible decisions. Should the RDC require technical information that the IMDC cannot supply, a mechanism exists for the EWTC to provide such advice direct to the RDC. The RDC recommends courses of action in drought mitigation and management through the Ministry of Finance to the Cabinet. Declarations of drought are, if necessary, made by the Office of the President.

Thus, the EWS can be seen as a mechanism for providing information upwards to the highest possible level of government for decision-making at a national scale. How does this work in practice and how is information promulgated within this system? What information, if any, comes to and from district governments, communities and individuals, lying outside the formal early warning system?

Members of the EWTC are drawn from technicians, managers and administrators within several ministries and sub-ministerial departments. These include the Ministry of Health, Central Statistical Office, Ministry of Local Government, Lands and Housing (MLGLH), Ministry of Agriculture, and the DMS. The EWTC

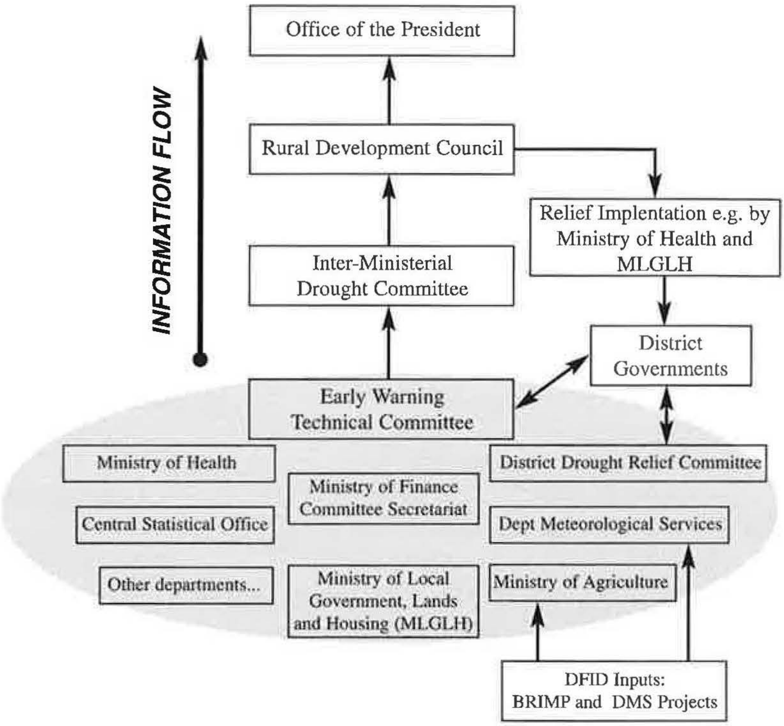

Figure 1 The drought early warning system in Botswana comprises a hierarchy of technical and advisory committees, responsible for information provision, decision-making and policy advice on all aspects of drought forecasting, preparedness, monitoring, management and relief. Most ministry representation includes more than one department or group. This is especially so in the case of the Ministry of Agriculture which has several groups in the EWTC and for which the Ministry's own Early Warning Unit acts as its EWTC co-ordinator.

also includes representation from districts in the form of the chairman and members of the District Drought Relief Committee.

The EWTC is the group that collects, sifts and assesses technical information, summarizing it for use by others. Its primary function is the regular assessment of environmental and socio-economic conditions on the ground throughout the country. Thus, it is essential for districts to provide some input. It is important to note that the District Drought Relief Committee, comprising senior officials from each district (such as district commissioners themselves), is in constant touch with district governments and through them to local communities, via extension services. Each district operates its own drought relief committee, dealing with all aspects related to drought. However, the IMDC formally receives all the information it obtains from districts, via the EWTC.

The EWTC liaises directly with each district government twice a year, generally around the middle of the rainy season, in January and at the end of the rainy season, in April. This liaison is achieved by the EWTC visiting *en masse*, the districts on a drought assessment tour. On these visits the EWTC obtains local feedback on local conditions during the recent past, previous months and seasons and it also obtains a local perspective on prospects for the following months.

For monitoring environmental conditions in Botswana, including assessment of recent rainfall and for forecasting possible drought, the information provided to the EWTC by the DMS and the Ministry of Agriculture is critical. Two years ago the EWTC secretary confirmed that the "only regular, timely and reliable information" available to the committee was that provided by the DMS. By now, in 1999, the situation has not changed significantly but the socio-economic and health information available to the committee is improving, to the extent that the committee is now ready to accept such improved information. The EWTC is beginning to integrate it with the environmental information available to provide more meaningful assessment of conditions and need.

Flow of basic information: the roles of the Ministry of Agriculture and Department of Meterological Services

Monthly rainfall, vegetation condition and fire scar data (much of the data most needed by the EWTC) are collected and supplied by the DMS. In the case of vegetation condition (status) and fire scar mapping, the basic data are enhanced by the Ministry of Agriculture Botswana Rangeland Inventory and Monitoring (BRIMP) Project[1], to form useful products that are accessible to the EWTC and presented to that committee at its monthly meetings. The products supplied by the DMS directly or via the DMS-BRIMP collaboration are appreciated by EWTC members and by its and the IMDC secretariat, as both timely and appropriate and because they greatly facilitate government decision-making.

The primary data needed to predict drought and to estimate its spatial variability is, of course, rainfall. The DMS supplies estimates of recent rainfall as standard map and tabular products, based on meteorological station rain-gauge data and supplemented by rainfall estimates derived from Meteosat geostationary satellite

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[1] The Ministry of Agriculture BRIMP Project began in 1996 and is funded by the UK Department for International Development (DFID). By 1999 the project has completed its Phase I. Tendering for a Phase II is expected later in 1999. BRIMP is organized into five teams, co-ordinated by a central management:

- the *Vegetation Inventory Team*, which organizes, archives and distributes vegetation information for users
- the *Seasonal Team*, which works with DMS to provide information each season on vegetation condition and rangeland fires
- the *Long-term Team*, which considers desertification issues
- the *Range User Team* which organizes participatory surveys, and
- the *Land Use Planning Team* which is currently primarily engaged in developing appropriate GIS techniques to develop vulnerability mapping by integrating environmental and socio-economic information.

Currently the BRIMP project 'teams' each comprise no more than one or two members of staff. Whilst such limited human resources have thus far created few problems, it is clear that loss of staff for any reason could severely limit the effectiveness of a team and thus the BRIMP Project.

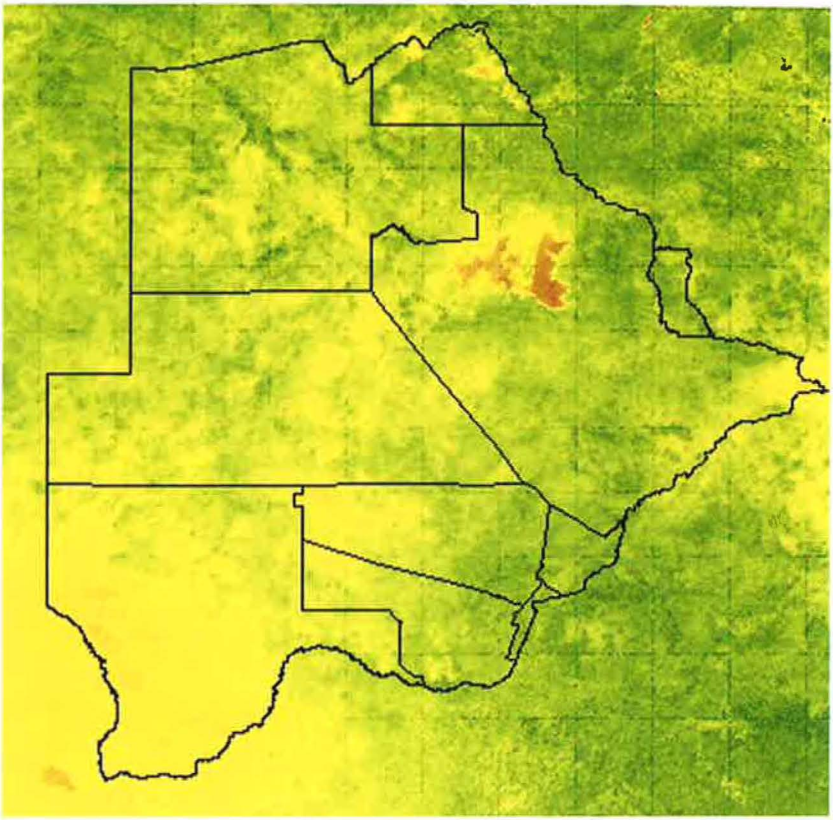

Figure 2 A maximum value composite normalized difference vegetation index (NDVI) image of Botswana.

(This image for the second dekad of January, 1998, shows a composite view of the status or photosynthetic activity of vegetation across the country. Dark green hues indicate healthy or growing vegetation and lighter colours indicate drier, less photosynthetically active vegetation. Areas of brown indicate zero or close to zero vegetation cover (e.g. salt or silica pans).

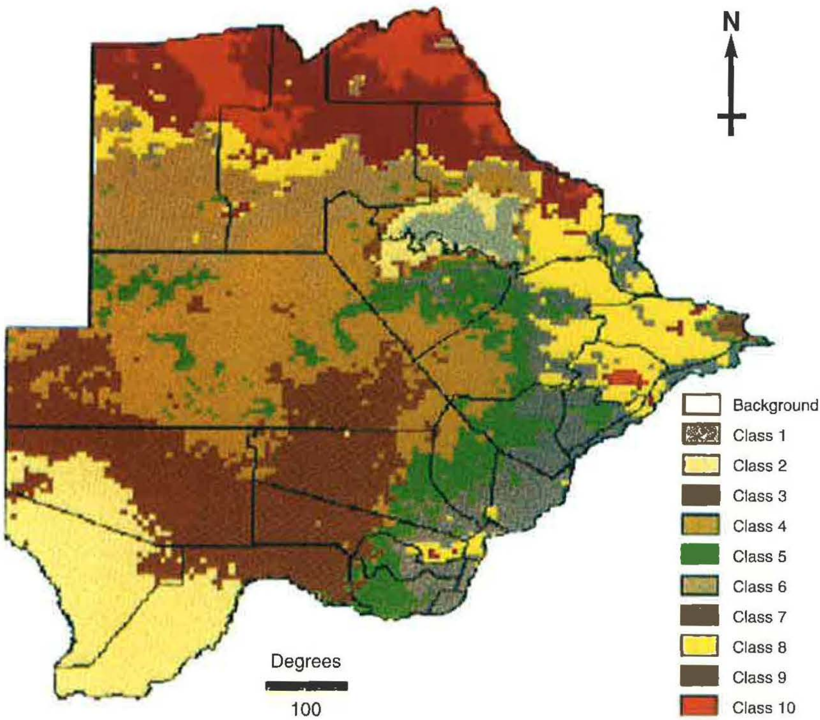

Figure 3 Simple 10 class stratification of Botswana, based on spectral response of the earth's surface recorded by the NOAA AVHRR instrument.

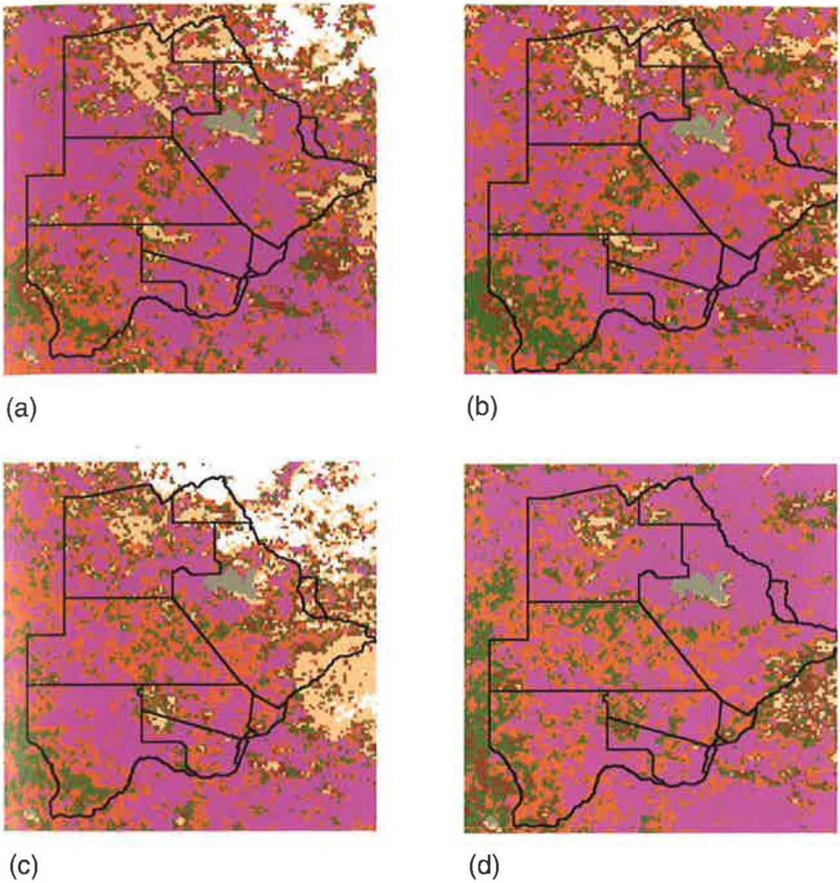

Figure 4 Vegetation status maps of Botswana, categorized into five classes from very low (tan colour), through average (green) to very high (dark red). Pans are shown as grey and cloud cover as white.

a) First dekad of January 1998
b) Second dekad of January 1998
c) Third dekad of January 1998
d) Monthly summary map for February 1998.

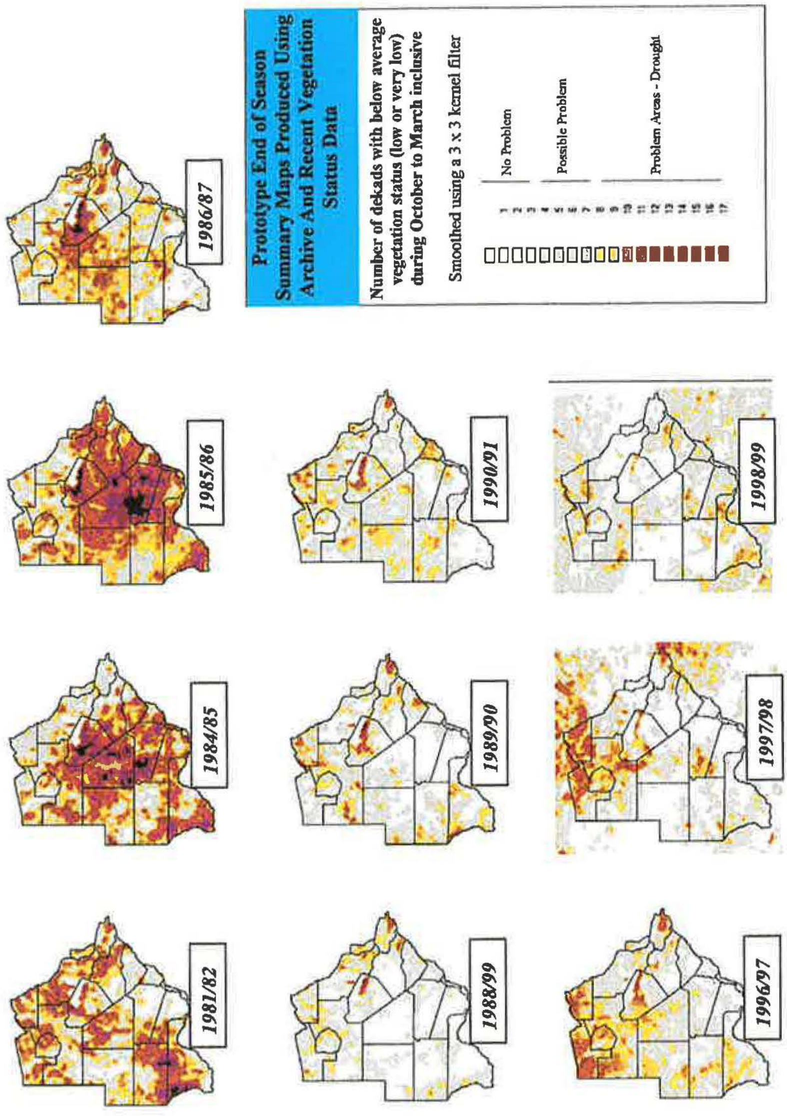

Figure 5 A selection of end of season summary maps of vegetation status, produced as prototype product by BRIMP in the Ministry of Agriculture and based on both the archive of NOAA AVHRR imagery available from 1981 and locally received NOAA data.

infra-red image sequences (using the Cold Cloud Duration method, see Milford and Dugdale, 1989; Bonifacio and Grimes, 1998). The latter effectively fill in the gaps between widely spaced rainfall stations, providing dekad (10-day) and monthly rainfall estimates for the whole country. Thus, contour maps and tables of recent rainfall are provided each month, in bulletins to the EWTC.

The DMS also supply dekadal and monthly maps of vegetation status (or vegetation condition) to the BRIMP team in the Ministry of Agriculture. Vegetation status maps such as these are generated using the standard Normalized Difference Vegetation Index (NDVI) method (see Figure 2), combining information from the visible and near-infrared channels of the NOAA advanced very high resolution radiometer (AVHRR) instrument. In this case, the AVHRR satellite images needed are collected daily by the DMS, using NRI's Local Application of Remote Sensing Techniques (LARST) low cost satellite receiver systems (Sear *et al.*, 1993). Global archives of AVHRR imagery also provide DMS and BRIMP with an opportunity to compare each season's vegetation condition with data for the period from 1981 to the present (see Sannier *et al.*, 1998). Classification of the country in 'spectral classes' based on the response of the surface (Figure 3) has allowed BRIMP to generate new and more useful products.

Individual classes vary from region to region and the classification folds into itself all determinants of surface spectral response (such as wetness, soil type and vegetation type). For each class, the statistics of the expected variation of NDVI through the year are calculated from the satellite archive. From this, the average and extreme conditions are determined for each spectral category and then the image data collected in each dekad or month can be rapidly compared with the archive statistics to produce estimates of vegetation status at that time and place.

Examples of these vegetation status maps are shown in Figure 4. Vegetation status is categorized into five classes, from much above average to much below average, where 'average' is defined with reference to the available archive. Further details of this methodology can be found in Sannier *et al.* (1998).

A problem with these maps, illustrated by the examples shown, is that by remote sensing convention, the higher status classes are shown in red and the lower classes in green. This is clearly counter-intuitive, as two EWTC members pointed out recently. In order to provide a better service to EWTC and other clients, DMS and BRIMP should consider generating maps using more appropriate colour coding and, for rapid, low cost dissemination, using monochrome in place of colour.

So, on an operational basis, the link between BRIMP and DMS staff focuses on providing in-season information on conditions on the ground and as such, the DMS works with the BRIMP Seasonal Team. Regular products include rainfall maps and maps of vegetation status, provided monthly to the EWTC and other clients.

The BRIMP Seasonal Team also takes DMS image data and generates fire and fire (burn) scar maps throughout the dry season, following the methods developed and described by Flasse and Ceccato (1996) and Flasse *et al.* (1997). These data are now seen as increasingly important to the national EWS in forecasting early rainy season rangeland conditions. This is because fire dramatically affects range quality and type and, therefore, affects the following season's vegetation status. Also, the setting of fires to reduce the disease hazard to livestock caused by ticks is a common practice. Government livestock specialists, however, are still not getting regular data direct from the DMS or BRIMP projects. Like other specialists, they only receive information through the formal mechanism of monthly EWTC meetings, if they are able to attend the meetings. This is a noteworthy weakness of the system. Crucial and well-constructed environmental information is not discussed within the wider EWS, other than formally at EWTC meetings. Currently, at the EWTC meetings, colourful maps are discussed and poured over, but EWTC members do not have an opportunity to take the map products away for further study, for comparison with previous information supplied or for correlation with their own data. It is now recognized by the BRIMP Project and DMS staff that significantly greater one-to-one liaison is required between data providers and other stakeholders in the national EWS and that opportunities for workshop-based training for a wide variety of data users should be enthusiastically taken up. There is further scope for improving access to information products via the (passworded) internet.

The BRIMP Seasonal Team works with its DMS colleagues to generate useful products that are simpler representations of the satellite-derived environmental data that can make a real impact on government decision-making. These products are being designed by BRIMP and DMS to be more easily understood by members of the EWTC, IMDC and RDC. For example, decision-makers in the EWS require simple views of current vegetation status. Recent work by the BRIMP Seasonal Team has resulted in a new prototype product – seasonal summary maps. The aim is to provide decision-makers with a single-picture view of the quality of the whole rainy season to date, at critical times through the season and, importantly, as quickly as possible after the end of the season.

The method integrates the dekadal category status through the rainy season, giving (for each 7 by 7 km square) the total number of 10-day periods which fall into key categories, such as below or much below average vegetation status. Thus, for example, assuming an 18-dekad long wet season, the resulting map will show how many of these dekads had low or very low vegetation status. To simplify further and to avoid using the unusual technical word 'dekad', the same results could be presented as the number of months with below average vegetation condition and would be comprehensive to lay-people and the public. The resulting end-of-season maps are now being analysed by BRIMP, DMS and EWTC colleagues to judge their likely impact.

Figure 5 shows a selection of the prototype end-of-season seasonal summary maps, generated by BRIMP, including the one generated for the end of the 1997–98 season, for comparison with the end of February 1998 vegetation status map shown in Figure 4. It is clear that the new product is easier to interpret than the basic vegetation status maps.

The whole series (1981–82 to 1998–99 inclusive) clearly shows the sequence of severe drought years through the early 1980s, with much of Botswana suffering drought conditions and poor rangeland status in 1982, 1984, 1985 and 1986, with widespread poor vegetation status continuing through to 1987. There then followed a series of generally better years until the early 1990s, when widespread drought re-occurred. Despite, the notorious El Niño in 1997–98, both that year and 1998–99 were relatively drought free in most areas of the country.

We anticipate that the real utility of such satellite-derived products will be seen when users from the national drought EWS and, hopefully, users in rural districts are trained in interpreting the seasonal summary maps, enabling them quickly to pin-point areas that have 'bucked the trend', for example, where a particular community has suffered from rangeland degradation or poor crop growth because of a significant lack of rainfall during a season that was not seen in neighbouring areas or more widely in the country. The images may also be able to detect the spatial extent and relative severity of other environmental events, for example, insect caused defoliation. Conversely, these 'images' could be used to help to assess the validity of district, local or individual claims for relief, based on poor crop yields or cattle death. A simple system was introduced in the mid-1990s in Zambia, to assess farmer claims for compensation after allegedly poor maize yields. Thus, at least in principle, such basic environmental information provides the decision-maker with a significant extra weapon in the armoury for targeting relief and for assessing claims.

In summary, the BRIMP Project Seasonal Team adds value to the basic environmental information on rainfall, vegetation and fire provided by the DMS. As indicated earlier, this collaboration is an example of a successful (and rare) inter-ministerial collaboration.

As well as providing important environmental information to the monthly EWTC meetings, the BRIMP and DMS staff report directly to the districts every 2 months. District administrators want easier to understand data. Indeed, they need these data to assess the situation in their areas on a regular basis. The BRIMP–DMS collaboration has taken on this requirement and is producing new prototype products, as described above. What is urgently needed now, for improving local early warning activity, is better ground truth data. Within the Ministry of Agriculture it is recognized that a next step will be to bring in range ecologists to assess the impact of the observed seasonal environmental variability on the rangeland in Botswana. In terms of arable agriculture, this approach should also lead to improved estimation of crop yields.

Ministry of Agriculture co-ordination

The critical Ministry of Agriculture input to the EWTC is co-ordinated by its own Early Warning Unit (EWU). It has an important role in handling secondary data, not provided by BRIMP and DMS, and ensuring that these data are reliable before they are presented to the EWTC. It picks up discrepancies and provides a co-ordinated Ministry of Agriculture view to the EWTC. The EWU was formed some years ago with initial funding from the Food and Agriculture Organization of the United Nations (FAO). It was supported by the Southern Africa Development Community (SADC) and was intended to be Botswana's drought early warning link to SADC. The EWU works with EWTC to produce the official *Botswana Food Security Bulletin* every 2 months throughout the rainy season.

Regional information provided by SADC is disseminated by the EWU and information provided by the EWTC is filtered and passed back to SADC. Today, the EWU sees its link to SADC as secondary to its co-ordinating role within the Ministry of Agriculture and central place in the EWTC for national drought early warning. The formal link between the EWU and SADC remains but it is more perfunctory than was previously the case. The EWU is funded and sustained solely by the Ministry, providing co-ordination of the Ministry's activities in the national EWS and it is seen as serving the interests of Botswana first and foremost. However, the EWU team recognizes that ideas on improving the national EWS occasionally come from other countries in southern Africa, via SADC. The EWU has an opportunity to analyse these and implement them in Botswana through the EWTC.

One early warning and targeting tool that is now recognized by the Government as having a potentially positive role to play, is vulnerability mapping. Recent efforts in the Ministry of Agriculture to set up systems for improved vulnerability mapping appear to have suffered from earlier insensitive approaches (by outside consultants) and the concept has not yet gained a wide ownership. BRIMP is testing GIS-based mapping, combining remote sensing data products with socio-economic information gathered by local survey, better to target vulnerable communities. Thus, this approach is essentially to add socio-economic indicators to basic environmental data. Elsewhere in the Ministry of Agriculture an attempt is being made to address vulnerability at a national level and sectorally, rather than geographically. Neither of these initiatives is currently receiving any significant funding and neither are they communicating with each other. This brings us to the question of sustainability.

Sustainability

As we have seen, some critical activities have been supported by outside funding, for example, FAO and SADC for the EWU, and DFID for BRIMP and components of DMS. The Government of Botswana appreciates the excellent value that these initiatives have added to the national drought EWS. The BRIMP–DMS collaborative work is directly attributable to the funding from DFID in the last 3 years. It is hoped that this collaboration will continue and the Government has every intention of supporting these activities locally if at all possible, but money is not unlimited, even in Botswana (where, we are told "diamonds are not forever"). As everywhere else inside and outside the developing world, such initiatives to provide improved environmental information have to fight hard for every cent they need to continue research and product development. As indicated earlier, resources are extremely limited, the entire BRIMP team comprises fewer than 10 persons. The DMS has a minimum of staff allocated to early warning product development and the EWU has currently two staff in post, seconded from elsewhere in the Ministry of Agriculture. This manpower resource constraint is a major concern and loss of staff to commercial concerns and to HIV is a current worry. There is still a need for more awareness of the added value that such applied research can provide to early warning but key government decision-makers do at least recognize the need for drought management to be placed centrally in its development planning.

IMPLEMENTATION OF DROUGHT RELIEF

The current acceleration of Botswana's national development planning makes the national drought EWS and its key technical committee, the EWTC, even more important now than it has been in the past. This is because the occurrence of droughts is becoming accepted as a chronic problem, rather than as individual emergencies, that arable agriculture may not be sustainable in Botswana and thus, coping with the future must include coping with frequent drought and sustaining development.

Once a drought has been declared as a national emergency, or within individual districts, the Nutrition Unit of the Ministry of Health works with the MLGLH to implement relief programmes. In Botswana, the system for distributing food relief to targeted populations is extremely efficient. First, there is a continuous campaign of monitoring the nutritional status of target populations (those likely to be most in need). Today, the nutritional status of the country's under-5s is used as a proxy for the whole population.

Each month, under-5s nutrition is monitored and analysed, district by district. To indicate the scale of the problem, the World Health Organization (WHO) sets a target of less than 10% of under-5s being malnourished. In Botswana, 18% of under-5s were malnourished in 1998. By 1999, this had dropped to 14%, but the Nutrition Unit team is not sanguine. Whilst it considers that the country *will* be able to continue to reduce levels of malnutrition in its under-5s and thus of the whole population, into the 21st century, it notes the paradox that the nutritional status of Botswana's population tends to go *down* in non-drought the years, rather than up. It is understood that this results from efficient feeding programmes undertaken during drought emergencies. Again, we note that collaboration between the ministries and the data providers is weak outside formal EWTC monthly meetings.

The MLGLH, Department of Local Government and Development operates the country's Remote Area Development Programme. It also provides information to the EWTC concerning projects in progress. After a declaration of drought, the Remote Area Development Programme co-ordinator implements relief projects that have been sanctioned by the RDC. These are district-based and labour intensive. Over the recent past the system has provided significant local job opportunities in rural areas and is a major component of the country's development activity, encouraging empowerment of local populations and income diversification away from arable and livestock farming. It is now anticipated that a permanent programme of public works improvement will be included in the national development planning process.

Within the MLGLH, the Social Welfare Group also implements part of the relief programme for drought, targeting the destitute. They identify, district by district, what is needed to sustain the population of permanently and temporally destitute, prior to delivering food relief. A current concern of the Social Welfare Group is that the rapid increase in HIV infection in the last few years has meant a similarly rapid increase in numbers of temporary and permanent destitute throughout the country, with some areas being hit harder than others. As the number of temporary and permanent destitute in Botswana has increased in recent years, so the need for regular relief each year has gone up, drought or no drought.

In years with no drought, there is a continuous trickle of government food aid (supplementary feeding) to selectively targeted vulnerable groups, specifically to the under-5s, lactating mothers, pregnant women and the destitute. Once drought is declared, on the other hand, food relief is distributed very widely. The relief programmes begin operations extremely efficiently. Immediately a drought declaration is made, food distribution to target populations starts within days to all in districts designated as suffering drought.

The food relief implementing agency within the MLGLH is the Procurement Office for the Supplementary Feeding Programme. Current policy dictates that, where possible, food is distributed using commercial carriers to four regional depots and from there to the 22 districts. Each district has a district food relief depot, administered by the district administration. Food is distributed from the district depots to individual communities, again generally by private contractors. Local stores are held at specific food distribution centres, such as designated health centres, clinics and schools. Relief implementation officials note that abuse of the system and minor corruption are occasionally seen but are not sufficient to cause great concern. Essentially this system of distributing food relief is extremely efficient once the RDC has advised the Ministry of Finance and the Office of the President that drought is a reality.

Local storage facilities appear to be the weak link in the chain. Each local community or village council is responsible for ensuring that the local storage facilities for food relief are maintained in adequate condition to ensure that food is not spoilt whilst awaiting final distribution to individuals. As a rule, these stores are checked for stock levels on a weekly basis. Deliveries from district depots are made approximately monthly during a drought emergency. The system is designed to ensure that food relief is distributed extremely quickly once an emergency is in place. This is achieved by using local and district level supplementary feeding facilities and lines of communication and distribution already in place. In this it succeeds but local wastage (through inappropriate or unhygienic local storage and to a lesser extent, to abuse and theft) is a problem, which in a poorer country might be a significant detriment to the whole early warning and relief programme.

The proof of success of these systems is zero malnutrition death attributable to drought (which officials proudly boast). Seeing drought as endemic or as a chronic problem is beginning to encourage decision-makers to develop long-term coping strategies for drought that are effectively indistinguishable from national development planning. As evinced here, a key system component is the provision of accurate environmental data from a small inter-ministerial collaboration. Providing accurate forecasts and accurately identifying and mapping spatial and temporal change is close to the current 'cutting edge' of applied science. Significant progress made with donor funding (DFID) in delivering useful environmental products may not be sustained if inadequate funding is available for continued adaptive research and technology transfer. Thus, a critical threat to the sustenance and development of the system is possible removal of core funding for this work.

BOTSWANA EARLY WARNING SYSTEM SWOT ANALYSIS

To summarize our main findings, we include below a tabulated Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis. This provides a simple view of this example of good practice in national drought early warning and relief implementation. It also highlights where the authors and the participants working with the system judge that improvements could or should be made.

Strengths

1.1	Drought EWS comprising national and regional representation and integrated within government decision-making structures
1.2	Wide acceptance of the EWS, from President to district level
1.3	Timely provision of key environmental information by relevant agencies
1.4	Development of new and improved products based on locally captured remotely sensed data (important for both timeliness and sense of 'ownership')
1.5	Inter-ministerial collaboration in the analysis and provision of these data
1.6	Environmental information accepted, appreciated and acted on by the key technical committee (EWTC)
1.7	Twice yearly multidisciplinary drought assessment tours by EWTC to districts

1.8 Effective and rapid provision of drought relief

1.9 Drought relief provided via a network of long standing institutions and structures

1.10 Provision of labour-intensive projects, leading to income diversification, such projects becoming a permanent feature of national development planning (NDP) (not just during drought emergencies).

1.11 Continuous campaign of monitoring the nutritional status of target populations (under-5s used as proxy for the whole population)

Weaknesses

1.1 Limited technical capacity in groups providing key environmental data

1.2 Limited manpower resources in technical groups of the EWS

1.3 Capacity to deliver key socio-economic and health-related information at required spatial scales may not match the ability to provide environmental information

1.4 Vulnerability mapping has not yet been approached sensitively or co-ordinated

1.5 Weak collaboration between the ministries and the data providers, as is dissemination of drought-related information outside formal EWTC meetings

1.6 Poor communication between central technical committees (EWTC) and district representatives outside formal drought assessment tours

1.7 Lack of dissemination of information in understandable forms to district and village levels

1.8 Lack of co-ordination of environmental, health and socio-economic information (these data not collated by a central agency or collaborative group but placed before EWTC meetings piecemeal)

1.9 Lack of understanding at community levels that drought is a chronic problem

1.10 Format of information products based on remote sensing may be counter-intuitive

Opportunities

3.1 Wide acceptance of EWS facilitates its faster evolution

3.2 Local generation and ownership of new/improved products in EWS

3.3 Electronic (internet) access to key DMS–BRIMP products for EWS colleagues and other users

3.4 Further inter-ministerial collaboration based on DMS–BRIMP success

3.5 To treat droughts as a chronic problem, as part of the development process and of the continuum of coping with change, rather than as individual emergencies

3.6 Permanent (labour intensive) development projects within the national development plan

3.7 From 3.4, to accept variability as normal, introducing and promoting new livelihood strategies, including new crops and income diversification

Threats	
4.1	Effective and rapid drought relief may promote a dependency culture
4.2	Inadequate funding for continued adaptive research and technology transfer
4.3	Limited technical ability and lack of training of technicians and administrators threatens the sustainability of the EWS, and...
4.4	...constraints on manpower availability limit the sustainability of the EWS
4.5	Variable quality of information available (e.g. lower from socio-economic providers) threatens accuracy of forecasts and thus decisions
4.6	Internal confusion and contradictions (e.g. DMS has in the past forecast poor rains and recommended planting drought resistant crops, such as sorghum, whilst at the same time the Ministry of Agriculture has continued to supply relief in the form of maize seed for re-sowing)

CONCLUSION

Drought is a developmental challenge and is endemic in Botswana. In Botswana, as in many other sub-Saharan countries, drought must be planned for and not just endured. The Botswana national drought EWS is a singular example of good practice. Key environmental data, required to forecast, identify and measure drought severity is provided to government through strong inter-ministerial collaboration. The flow of environmental information up to decision- and policy-making bodies is formalized, regular and is generally considered sufficient for the purpose.

The EWS has relevant political influence to allow the RDC to make appropriate decisions concerning each drought emergency as it arises. Implementation of food relief is targeted and rapid and at the policy level, droughts are better understood than ever before. They are beginning to be seen as a part of life in Botswana and not as isolated emergencies. The provision of this key environmental information can only be handled effectively at a national level and by a central agency or group of collaborating agencies.

Until now the EWS has focused on arable farmers as its most important client constituency. Today, there is an increasing recognition at the centre that arable farming may not be sustainable in the long term in Botswana, but arable farmers are still identified publicly as the community that requires most help in time of drought. Many rural communities cannot accept that they might consider not planting – they "want to be farmers" (according to the Kgatleng District Commissioner and central government officials). Most, it seems, do not yet appreciate that they *may have* other options, which are perhaps more sustainable in Botswana's climate. This exemplifies a significant weakness of the current drought EWS. There is a lack of effective communication with climate-vulnerable groups in rural communities and a lack of feedback from them.

The Botswana example indicates the effectiveness with which information can be assimilated in the decision-making process. However, it is important to realize that this crucial flow information is currently dependent on only a few small groups comprising little in the way of manpower and few resources. At the same time crucial information is also required in the form of feedback from districts and ultimately from individuals impacted by drought. A more comprehensively integrated approach is essential. This must include more participation from the 'grass roots', improved flow of appropriately interpreted information to and from communities and individuals and better, more co-ordinated vulnerability mapping. An urgent need now is to get information to and from rural communities more efficiently. Participants in the EWTC recognize that extension staff working in the field need much better training in interpretation of the environmental and socio-economic information available from the centre. They also need significantly better training in targeting this information more successfully to their clients in the villages. Improving extension workers' 'marketing skills' was specified as the first priority by an EWTC member.

It is also noted that the Government of Botswana plans to spend more time and effort improving its information dissemination via the media in order to decentralize knowledge and increase confidence in the community-level and district-level decision-making. An idea whose time has come is for district-based benchmarking to aid the uptake of best practice within the country. The issue is essentially one of packaging information, as each level of decision-making from village to RDC has a different level of understanding in terms of its information requirements. The key issues for vulnerable populations are how the national food relief strategy may evolve to promote deeper food and economic security and whether the country as a whole can accept that arable agriculture may not be sustainable in the future.

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ABBREVIATIONS AND ACRONYMS

AAU	ActionAid Uganda
ARTEMIS	Africa Real Time Environmental Monitoring Information System
AVHRR	advanced very high resolution radiometer
BRIMP	Botswana Rangeland Inventory and Monitoring
BULOG	Indonesian National Logistics Agency
CBO	community-based organization
CCD	cold-cloud duration **or** charged coupled device
CCP	critical control point
CITA	Centro Nacional de Ciencia y Tecnologia de Alimentos
CMD	cassava mosaic disease
CPP	Crop Protection Programme
DAREP	Dryland Applied Research and Extension Project
DFID	Department for International Development
DLCO-EA	Desert Locust Control Organization for Eastern Africa
DSS	decision support systems
DMS	Department of Meteorological Services
EIS	environmental information system
ELMAT	Eritrean Locust Management and Analysis Tool
ENSO	El Niño-Southern Oscillation
EWS	early warning system
EWTC	Early Warning Technical Committee
EWU	Early Warning Unit
FAO	Food and Agriculture Organization of the United Nations
FDSS	Fumigation Decision Support System
FPR	farmer participatory research
FSTAU	Food Security Technical and Administrative Unit
GIS	geographical information system
GMP	good manufacturing practices
GPS	global positioning system
HACCP	Hazard Analysis Critical Control Point
IMDC	Inter-Ministerial Drought Committee
INR	Institute of Natural Resources
IPM	integrated pest management
IRISCP	International Research Institute for Seasonal-to-interannual Climate Prediction
IRRI	International Rice Research Institute
IRS	Indian Remote Sensing
ITK	indigenous technical knowledge
ITDG	Intermediate Technology Development Group
KARI	Kenya Agricultural Research Institute
LARST	Local Application of Remote Sensing Techniques
LPK	local people's knowledge
M & E	monitoring and evaluation
MLGLH	Ministry of Local Government, Lands and Housing

NAES	National Agricultural Extension System
NARS	national agricultural research system
NDVI	normalized difference vegetation index
NEAP	national environmental action plan
NERC-ESRC	National Environment Research Council - Economic and Social Council
NGO	non-governmental organization
NMS	National Meteorological Service
NOAA	National Oceanic and Atmospheric Administration
NOAA OGP	NOAA Office of Global Programs
NR	natural resource
NRI	Natural Resources Institute
PAR	participatory action research
PFD	process flow diagram
PRA	participatory rural appraisal
RDC	Rural Development Council
REWS	Regional Early Warning System
RRA	rapid rural appraisal
SA	Selective Availability
SADC	Southern Africa Development Community
SALLFF	South Africa Long Lead Forecasting Forum
SAP	Structural Adjustment Policy
SARCOF	Southern Africa Regional Climate Outlook Forum
SAWB	South African Weather Bureau
SME	small to medium-scale enterprise
SPOT	Système Pour l' Observation de la Terre
SPS	Standard Positioning System
SRF	systematic reconnaissance flight
START	System for Analysis Research and Training
SWOT	Strengths, Weakness, Opportunities and Threats analysis
TOT	transfer of technology
UKMO	UK Meteorological Organization
UNEP	United Nations Environmental Programme
USDA	United States Department of Agriculture
UTM	Universal Transverse Mercator
WHO	World Health Organization